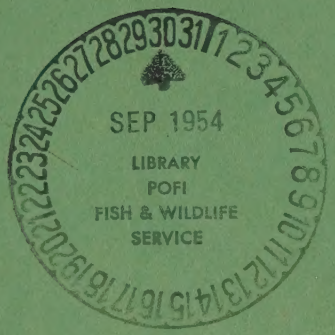
Studies

195



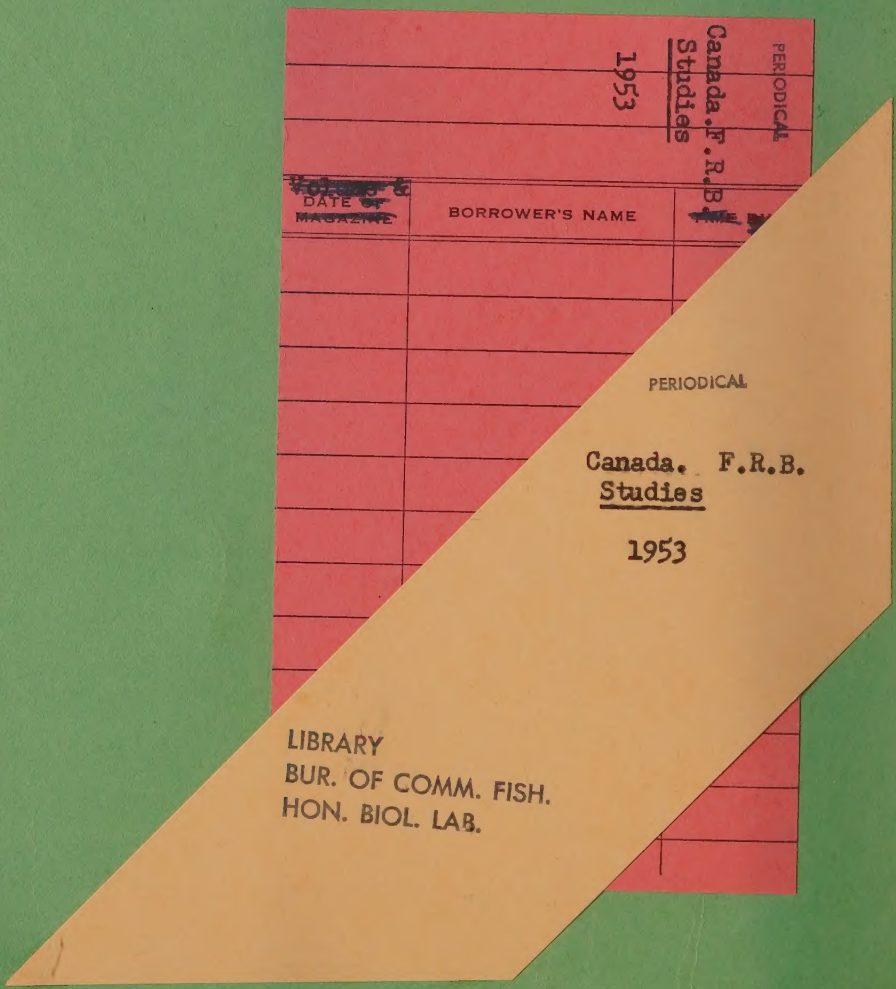
STUDIES

1953

FROM THE STATIONS OF THE

FISHERIES RESEARCH BOARD OF CANADA

342 TO 369


PERIODICAL
Canada.F.R.B
Studies
1953
DATE
BORROWER'S NAME
PERIODICAL
Canada. F.R.B.
Studies
1953
LIBRARY
BUR. OF COMM. FISH.
HON. BIOL. LAB.

STUDIES

1953

FROM THE STATIONS OF THE
FISHERIES RESEARCH BOARD OF CANADA

—CONTENTS—

342	Contributions to the life-history of the sockeye salmon (No. 37)	D. R. Foskett
343	Results of the west coast of Vancouver Island herring investigation	J. C. Stevenson, A. S. Hourston, K. J. Jackson, D. N. Outram
344	Review of Canadian Pacific oceanography since 1938	John P. Tully
345	Notes on the behaviour of fresh water entering the sea	John P. Tully
346	How Passamaquoddy produces sardines	A. G. Huntsman
347	Semimicrodetermination of dissolved oxygen	E. L. Harper
348	Two records of *Berardius bairdi* from the coast of British Columbia	Gordon C. Pike
349	The hydrogen value-refractivity relationship of unsaturated fatty acids of natural origin	F. A. Vandenheuvel, E. H. Farmer
350	A new alkali isomerization procedure	F. A. Vandenheuven, G. H. Richardson
351	Ribose and the maillard reaction in fish muscle	H. L. A. Tarr
352	Preliminary report on the growth of finback whales from the coast of British Columbia	Gordon C. Pike
353	Swarming of *Nereis succinea* (Leuckart) off the east coast of Canada	C. & E. Berkeley
354	Canada's fisheries, and their Atlantic situation	A. G. Huntsman
355	A seawater sampling bottle	R. L. I. Fjarlie
356	Research in salmon migration over high dams. The nature of the biological problem	J. R. Brett
357	Notes on fishes collected from Lake Winnipeg region	J. J. Keleher
358	Wind currents and storm effects on water movement at Sambro lightship	H. B. Hachey, N. O. Fothergill
359	Effects of compensatory mortality upon population abundance	W. E. Ricker
360	The maillard reaction in flesh foods	H. L. A. Tarr
361	Arctic and Subarctic marine ecology: Immediate problems	M. J. Dunbar
362	Contributions to the life-history of the sockeye salmon (Paper 38)	D. R. Foskett
363	Results of investigation of the herring population on the west coast and lower east coast of Vancouver Island in 1952-53	J. C. Stevenson, D. N. Outram
364	Effects of protective and regulatory legislation upon the Pacific herring and halibut fisheries	W. E. Ricker
365	Arctic or polar cod, *Boreogadus saida*, in Miramichi Bay, New Brunswick	R. A. McKenzie
366	II. Knowledge of divisions of stocks of cod, haddock, redfish and American plaice in subareas 3 and 2 of the Northwest Atlantic Convention area	Wilfred Templeman
367	Identification of major groundfish stocks in subarea 4 of the Northwest Atlantic Convention area	W. R. Martin
368	Long term changes in hydrographic conditions and corresponding changes in the abundance of marine animals	Wilfred Templeman, A. M. Fleming
369	Summary of Canadian groundfish research in the Convention area during 1952	Wilfred Templeman

(Reprints of articles published by Board scientists other than in the publications of the Board)

APPENDICES

CONTRIBUTIONS TO THE LIFE-HISTORY OF THE SOCKEYE SALMON (No. 37)

By D. R. Foskett, M.A., Pacific Biological Station, Nanaimo, B.C.

INTRODUCTION

The excellent packs of sockeye in the Rivers Inlet and Smith Inlet areas, 102,565 cases and 49,473 cases, following last year's high packs were indeed encouraging. The Skeena River pack of 61,694 cases was equal to the average for the last ten years. The Nass River pack of 24,405 cases was considerably above the average for the past thirty-nine years of 20,200 cases.

One of the problems in connection with the utilization of the sockeye runs is that of the jacks or 3-year-old males. Because of their small size these are taken by the commercial gear in small numbers only, and yet may be exceedingly numerous on the spawning-grounds, as is shown below for both the Rivers Inlet run and the Skeena River run in 1951. Unfortunately, no experiments known to the author on the inheritance of the tendency toward early maturity have been carried past the first generation, and thus they cannot be considered conclusive. Also, it cannot be said at the present time whether the number of jacks on the spawning-grounds is increasing, since accurate numerical records over a fair number of years, such as are obtained by counting-fences, are not available at present. It is known that certain streams will tend to have large percentages of jacks while other streams will seldom have any jacks present.

DESIGNATION OF AGE-GROUPS

Two outstanding features in the life-history of the fish have been selected in designating the age-groups; namely, the age at maturity and the year of its life in which the fish migrated from fresh water. These are expressed symbolically by two numbers—one in large type, which indicates the age of maturity, and the other in small type, placed to the right and below, which signifies the year of life in which the fish left the fresh water. The age-groups which are met most commonly are:—

3_1, 4_1—the " sea-types " or fish which migrate in their first year and mature in their third and fourth year respectively.

3_2, 4_2—the " grilse " or " jacks," usually males, which migrate in their second year and mature in their third year, or migrate in the third year and mature in their fourth year.

4_2, 5_2—fish which migrate in their second year and mature in their fourth and fifth year respectively.

5_3, 6_3—fish which migrate in their third year and mature in their fifth and sixth year respectively.

6_4, 7_4—fish which migrate in their fourth year and mature in their sixth and seventh year respectively.

As is indicated in the discussion of the Nass River age-groups, some doubt still exists as to the particular point at which a check is sufficiently distinct to warrant recognition as marking the completion of a year. This is particularly the case when the analysis of the fresh-water residence of sockeye is considered because of the small number of circuli involved and the variability of their numbers in different areas of a large water-

shed. Research is now being carried on by the Fisheries Research Board of Canada in two areas where doubt exists as to the length of fresh-water residence—Lakelse Lake and Port John Lake—and it is hoped that the results obtained in these areas will help in obtaining a clearer understanding of the situation in other areas, such as the Nass watershed, where the absence of field surveys and stations makes it difficult to determine the correct interpretation of doubtful scales.

The Nass River run is the most northerly of the sockeye-salmon populations in British Columbia which is fished by our fishermen. This population has therefore been placed first in the analyses this year, and the other populations have been placed in order as one proceeds south along the coast. This arrangement would be upset less by the subsequent addition of new areas. Extra tables which may be introduced, as in the Rivers Inlet report this year, will, however, be placed at the end of the regular tables to preserve the numbering for comparative purposes.

1. THE NASS RIVER SOCKEYE RUN OF 1951

(1) General Characteristics

The sockeye-pack of 24,405 cases was very good for the Nass River, where the average for the past ten years has been 15,545 cases. The escapement was reported to be adequate to the Meziadin area, which reportedly constitutes the main spawning area for sockeye in this system.

(2) Age-groups

The three age-classes 4_2, 5_3, and 6_3, forming 41, 31, and 13 per cent respectively of the 1951 sample of 2,901 fish (Tables I to VI), made up the bulk of the Nass River sockeye-catch. The 5_2 age-class was represented by 239 fish or 8.6 per cent of the sample (Tables II and III). The 3_1 and 4_1 age-classes, comprising 10 and 151 individuals respectively, formed 5.8 per cent of the sample (Tables II and III). There is some doubt as to the legitimacy of these age-classes, since there is in many cases a very slight check which could be interpreted as a year's growth in fresh water. The samples of this type, coming chiefly in the early part of the sampling, have been interpreted as " sea-run " fish in some years, for example, Paper 28, 1942, of this series, and probably as 4_2 and 5_2 age-classes in other years when the checks were more distinct. Research has already been instigated to determine more exactly what may be interpreted as a year check in the fresh-water growth, and it is hoped that this will also aid in the interpretation of salt-water checks, especially in the first year of salt-water growth when changing physiological as well as environmental factors could be expected to have an effect on the configuration of the scale circuli.

(3) Lengths and Weights

Though the Nass sockeye were quite large (Tables II and III), there was nothing outstanding in the samples, the season's averages falling within the upper range of the average lengths and weights recorded in the past ten years (Tables IV and V).

(4) Distribution of the Sexes

The over-all sex ratio of 49.4 to 50.6 is as near equality as one could expect. Only in the 6_3 age-class is there any really significant deviation from an even sex ratio, the group being 70 per cent males and thirty per cent females.

2. THE SKEENA RIVER SOCKEYE RUN OF 1951

(1) General Characteristics

The Skeena pack of 61,694 cases was equal to the average pack of 61,720 cases for the past ten years. The escapement was reported to be light. The Babine area spawning

population suffered tremendous losses due to a slide in a canyon about 40 miles below Babine Lake.

(2) Age-groups

The Skeena River sockeye sample of 1951 was composed chiefly of 5_2 fish (61.5 per cent), and the bulk of the remainder (32.5 per cent) was of 4_2 fish (Table VII). The 5_3 age-class was represented by 130 sockeye and the 6_3 age-class by 38 sockeye, giving percentages of 4.4 and 1.3 respectively (Tables VIII and IX). Jacks were of minor importance in the catch, though figures from up-river investigations* indicate that they were more numerous in the run than was shown by the catch.

The presence of one or two individuals in several additional age-classes is to be expected in a large sample and does not of necessity indicate anything unusual in the population.

(3) Lengths and Weights

The Skeena River sockeye were large in 1951 (Tables VIII and IX). The 4_2 age-class males at 22.7 inches were not unusual, though the females at 22.6 inches were the largest since 1941 (Table X). Both the 5_2 males at 25.9 inches and the females at 24.8 inches were the largest in the past ten years (Table X). Neither the 5_3 nor 6_3 fish were unusual in either length or weight. The 4_2 males, in weight as in length, were within the limits of variation of the past ten years (Tables X and XI). However, the 4_2 females and both sexes of the 5_2 age-class had the highest average weight recorded since 1940 (Table XI).

(4) Distribution of Sexes

The over-all sex ratio of 39 males to 61 females reflects the condition in the two most prevalent age-classes, the 4_2 group having 41 per cent males and the 5_2 group 37 per cent males (Table XII). In the 5_3 and 6_3 groups the ratio was 53 males to 47 females.

3. THE RIVERS INLET SOCKEYE RUN OF 1951

(1) General Characteristics

The Rivers Inlet sockeye run of 1951 produced a very satisfactory pack of 102,565 cases (Table XIII). The escapement, classed as moderate to heavy, was, in the opinion of the writer, adequate in most of the streams in the area.

(2) Age-groups

The catch was largely 5_2 fish (59.7 per cent), of large size, the average weight of the age-class being 7.8 pounds (Tables XV and XVII). The 4_2 age-class fish, which comprised 38.0 per cent of the run, were also of large size, the average weight being 5.2 pounds (Table XV). The 5_3 class was represented by 17 fish (1.2 per cent). The 6_3 age-class was represented by 9 fish (0.6 per cent), and the 3_2 age-class or jacks were represented by 4 fish (0.3 per cent). As will be shown later, the percentage of jacks in the commercial catch does not represent the percentage of jacks in the run. One fish was present in each of the following age-classes: 4_1, 6_2, and 5_4.

(3) Lengths and Weights

The average length and weight of the Rivers Inlet sockeye in 1951 was high. In the 4_2 age-class the average length of 21.9 inches for both males and females (Table XVI) has not been exceeded since 1938. The 5_2 age-class averages of 25.8 inches for males and 24.8 inches for females are high, the former having been exceeded only in 1950 and the latter equalled only in 1940 (Table XVI).

* *See* Aro, "The Babine River Salmon Escapement in 1951," and Foskett, "The Effect of the Babine Slide on the 1951 Sockeye Run," in No. 90, Progress Reports of the Pacific Coast Stations of the Fisheries Research Board of Canada, March, 1952.

Though high, the 5.2-pound average for 4_2 age-class males and the 5.0-pound average for females of this group have been exceeded several times in the past. The average weight of the 5_2 age-class males, 8.6 pounds (Table XVII), has never been exceeded in this area, though the average for the females in the same group, 7.4 pounds (Table XVI), is the second highest, having been exceeded in 1927, when an average of 7.6 pounds was recorded.

(4) Distribution of Sexes

The over-all sex ratio of 43.9 per cent males and 56.1 per cent females (Table XVIII) in the 1,420 samples does not reveal the peculiarities of the sex distribution. The 4_2 age-class is largely males (65.7 per cent), while the 5_2 age-class is predominantly females (69.8 per cent). The 5_3 and 6_3 age-classes are also largely female.

(5) Spawning-ground Samples

Through the courtesy of the Dominion Fisheries Department and especially Inspector M. P. Houghton, the author was able to examine the Rivers Inlet spawning-grounds and obtain samples of the spawned sockeye. Due to the advanced state of absorption of the scales of these fish, age determinations were not possible by this means. However, comparison of the lengths of these fish with those sampled at Goose Bay is enlightening.

As may be seen from Table XXV, the male sockeye were present in the sample in three main length-groups. Those between 13 and 16½ inches may be presumed to be the 3_2 age-group, the jacks, which were so sparsely represented in the commercial catch. The next group, between 18½ and 20½ inches, may be presumed to represent the 4_2 fish. The third group, from 24 to 29 inches, presumably would be predominantly 5_2 age-class fish.

The female fish do not separate as readily into groups as the male fish. There is a range from 20½ to 24½ inches which has a few samples throughout its length with no main concentration. Then there is a concentration of fish in the range from 25 to 26 inches. In comparing these figures with Table II, it is seen that these lengths coincide with the range of the 4_2 fish and the smaller 5_2 fish in the first case and with the larger 5_2 fish in the second case.

Thus we see that the spawning-ground samples do not reflect the catch samples but rather complement them. This is not only so in the length frequencies, but also may show up in the sex ratios, as evidenced by the following excerpt from Inspector Houghton's report on the Asclum River: "The sex ratio of the 4 and 5 year-classes favoured females in the younger fish and males in the older class." Similar remarks were made with regard to the four other streams in the area in which sex ratios were given separately for the larger and smaller fish. This is opposite to the situation in the commercial catch, as shown previously.

(6) Predation

The situation with regard to predators in this region warrants a few words. Both seals and bears are numerous. The former enter the lake and hang about off the mouths of the streams. Here they have a very high potential for damaging the sockeye which frequent these areas in large schools while ripening preparatory to entering the stream and spawning. It is possible that some type of weir could be placed in the lower part of Owikeno Lake to exclude seals from the spawning areas of the system.

Grizzly bears are found on the redds, and until it is known whether they take spawned or unspawned salmon, their effect is not known. Their habit at times of entering the river in huge bounds might be presumed to frighten off fresh fish and leave the more nearly spent fish to be captured. The effect of their fishing when wading in the stream may be quite different. However, an investigation might well be undertaken, preferably as a joint enterprise with the British Columbia Game Commission, in order to settle this controversial question.

Nothing is known at present with regard to the indigenous fish population of Owikeno Lake, either as predators on, or competitors with, the sockeye.

(7) Discussion

From an examination of Tables XIV and XXV it is evident that either the sampling on the spawning-grounds was not adequate or the gill-net fishery selects the catch from the medium-size fish or probably both. Unfortunately, samples were obtained at only one period during the run, and though the distribution covered most of the spawning areas, it did not cover the early runs nor the latest runs.

However, it is felt that the results do show that the escapement is predominantly of the smaller and larger sockeye and that this situation is especially true of the males. Unfortunately, the author knows of no experiments upon the inheritance of various characters in the sockeye which have been taken beyond the first generation. Thus it is impossible to say what effect such a continued selection is apt to have on the stock. Many factors could have an influence on size at maturity. Prediction can never be completely satisfactory until we know the factors controlling growth and maturity.

(8) Summary

The Rivers Inlet sockeye run of 1951 was very satisfactory both from the catch and escapement angles. The bulk of the escapement appears to come from the extreme ends of the size range, though relatively more females than males in the middle sizes are found on the spawning-grounds. While predators are numerous in the Owikeno Lake area, the greatest amount of damage is probably done by seals off the mouths of the creeks. That gill-net selection takes place is evident from the catch and escapement samples, but at present no definite statements can be made regarding long-term effects on the population.

4. THE SMITH INLET SOCKEYE RUN OF 1951

(1) General Characteristics

The Smith Inlet pack of 49,473 cases, the highest recorded, was more than double the twenty-six-year average of 22,100 cases. The excellent condition of the fish was shown in their average weight. There was a heavy escapement to the spawning-grounds.

(2) Age-groups

Of the 673 sockeye in the sample, 521 (77.4 per cent) were in the 5_2 age-class and 147 (21.8 per cent) were in the 4_2 age-class (Table XIX). Both the 6_2 and 5_3 age-classes were represented by 2 fish and the 3_2 or jack class was represented by 1 fish.

(3) Lengths and Weights

The 4_2 age-class had average lengths of 22.8 inches for the males and 22.0 inches for the females (Table XX). The 5_2 age-class had average lengths of 25.6 inches and 24.8 inches respectively for the males and females. The 5_2 lengths are greater than the averages recorded since 1945, when length records commence in this area. The average weights of the fish in the two main age-classes were 6.0 and 5.2 pounds respectively for the males and females in the 4_2 age-class and 8.2 and 7.3 pounds in the 5_2 group (Table XXI). Records in the other age-classes are too sparse to justify comparisons.

(4) Distribution of Sexes

The peculiar sex ratios shown in the Smith Inlet sockeye records point to some connection between sex and age of maturity, in this population at least. As has been normal in the past, the 4_2 age-class again showed an excess of males (72 per cent), while the 5_2 age-class showed more females (58.5 per cent) (Table XXIV).

Table I.—Nass River Sockeyes, Percentages of Principal Age-groups in Runs of Successive Years and Packs

Year	Percentage of Individuals			
	4_2	5_2	5_3	6_3
1912 (36,037 cases)	8	27	63	2
1913 (23,574 cases)	15	12	71	2
1914 (31,327 cases)	4	41	45	10
1915 (39,349 cases)	19	14	59	8
1916 (31,411 cases)	9	17	66	8
1917 (22,188 cases)	10	15	71	4
1918 (21,816 cases)	30	16	45	9
1919 (28,259 cases)	7	22	65	6
1920 (16,740 cases)	8	14	72	6
1921 (9,364 cases)	10	7	75	8
1922 (31,277 cases)	6	2	91	1
1923 (17,821 cases)	11	6	77	6
1924 (33,590 cases)	4	3	91	2
1925 (18,945 cases)	23	8	67	2
1926 (15,929 cases)	12	12	63	13
1927 (12,026 cases)	8	7	81	4
1928 (5,540 cases)	30	6	61	3
1929 (16,077 cases)	25	9	60	6
1930 (26,405 cases)	28	15	54	3
1931 (16,929 cases)	10	17	67	6
1932 (14,154 cases)	28	4	61	7
1933 (9,757 cases)	35	7	55	3
1934 (36,242 cases)	13	9	74	4
1935 (12,712 cases)	11	10	73	6
1936 (28,562 cases)	16	7	67	10
1937 (17,567 cases)	22	4	68	6
1938 (21,462 cases)	21	4	70	5
1939 (24,357 cases)	14	13	66	7
1940 (13,809 cases)	23	8	59	10
1941 (24,876 cases)	37	7	52	4
1942 (21,085 cases)	22	7	66	5
1943 (13,412 cases)	5	13	67	15
1944 (13,083 cases)	15	15	32	38
1945 (9,899 cases)	46	11	37	6
1946 (12,511 cases)	13	12	72	3
1947 (10,849 cases)	15	12	56	17
1948 (13,181 cases)	12	16	60	12
1949 (9,268 cases)	39	6	48	7
1950 (27,286 cases)	3	19	71	6
1951 (24,405 cases)	41	9	31	13

Table II.—Nass River Sockeyes, 1951, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals																		Total
	3_1		4_1		4_2		5_2		5_3		6_3		7_3		6_4		7_4		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
14	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
14¼	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
14½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
14¾	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
15¼	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
15½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
15¾	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16¼	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16¾	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17¼	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17½	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
17¾	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18¼	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18¾	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19¼	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19¾	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—	3
20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
20¼	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1
20½	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	2
20¾	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
21	—	—	—	—	1	2	—	—	—	—	—	—	—	—	—	—	—	—	3
21¼	—	—	1	1	1	3	—	—	—	—	—	—	—	—	—	—	—	—	6
21½	—	1	—	—	—	10	—	—	—	—	—	—	—	—	—	—	—	—	11
21¾	1	—	—	1	3	7	—	—	—	2	—	—	—	—	—	—	—	—	14
22	—	—	—	2	3	29	—	—	—	3	—	—	—	—	—	—	—	—	37
22¼	—	—	—	3	5	50	—	—	1	8	—	—	—	—	—	—	—	—	67
22½	2	—	—	4	14	77	1	2	1	18	—	—	—	—	—	—	—	—	119
22¾	—	—	—	3	26	60	—	1	—	13	—	—	—	—	—	—	—	—	103
23	—	—	1	9	25	94	—	2	7	28	—	1	—	—	—	—	—	—	167
23¼	1	1	—	10	29	70	—	4	3	30	—	—	—	—	—	—	—	—	148
23½	—	1	—	14	60	80	—	5	15	40	—	—	—	—	—	—	—	—	215
23¾	—	—	2	13	49	50	—	5	18	31	—	1	—	—	—	—	—	—	169
24	—	—	4	6	67	37	1	10	21	41	—	1	—	—	—	—	—	—	188
24¼	—	—	1	6	65	13	3	9	22	59	1	3	—	—	—	2	—	—	184
24½	—	—	2	2	62	13	6	5	26	53	—	4	—	—	—	1	—	—	174
24¾	—	—	3	—	32	8	3	19	29	33	3	2	—	—	—	3	—	—	135
25	—	—	12	2	35	6	6	20	52	36	1	4	—	—	2	1	—	—	177
25¼	—	—	5	2	28	1	4	13	39	27	1	4	—	—	—	3	—	1	128
25½	1	—	9	—	8	—	9	9	39	18	1	8	—	—	2	2	—	—	106
25¾	—	—	3	—	5	—	8	8	26	12	3	6	—	—	2	2	—	—	75
26	—	—	7	1	2	—	18	7	34	9	10	4	—	—	—	1	—	—	93
26¼	—	—	8	—	2	—	4	2	27	1	14	9	—	—	1	—	—	—	68
26½	—	—	4	—	1	1	10	—	14	1	20	10	—	—	—	—	1	—	62
26¾	—	—	1	1	—	—	7	1	9	—	15	9	—	—	—	—	—	—	43
27	—	—	1	—	—	1	11	4	5	—	27	11	—	—	—	—	—	—	60
27¼	—	—	2	—	—	—	6	—	1	—	22	6	—	—	—	—	—	—	37
27½	—	—	2	—	—	—	4	—	1	—	26	14	—	—	1	—	—	—	48
27¾	—	—	—	—	—	—	5	—	—	—	20	4	—	—	—	—	—	—	29
28	—	—	1	—	—	—	5	—	1	—	29	6	—	—	—	—	—	—	42
28¼	—	—	—	—	—	—	2	—	—	—	19	1	—	—	—	—	—	—	22
28½	—	—	2	—	—	—	—	—	—	—	20	3	—	—	—	—	—	—	25
28¾	—	—	—	—	—	—	—	—	—	—	6	—	—	—	—	—	—	—	6
29	—	—	—	—	—	—	—	—	—	—	14	—	1	—	—	—	—	—	15
29¼	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	3
29½	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	3
29¾	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	2
30	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1
Totals	7	3	71	80	527	613	113	126	391	464	261	111	1	—	8	15	1	1	2,793
Average lengths	22.0	22.8	25.6	23.5	24.0	23.1	26.2	24.8	25.1	24.1	27.4	26.4	29.0	—	25.8	25.1	26.5	25.3	24.5

Table III.—Nass River Sockeyes, 1951, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals																		Total
	3_1		4_1		4_2		5_2		5_3		6_3		7_3		6_4		7_4		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1¼	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1¾	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2¼	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
2½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2¾	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
3¼	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3½	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	2
3¾	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	2
4	1	—	—	—	3	11	—	—	—	2	—	—	—	—	—	—	—	—	17
4¼	—	—	1	2	1	18	—	—	—	5	—	—	—	—	—	—	—	—	27
4½	—	1	—	4	13	67	—	2	1	19	—	—	—	—	—	—	—	—	107
4¾	1	—	—	3	11	100	—	—	4	27	—	—	—	—	—	—	—	—	146
5	2	—	1	7	29	122	1	2	7	41	—	—	—	—	—	—	—	—	212
5¼	—	—	—	11	34	86	—	4	5	49	—	1	—	—	—	—	—	—	190
5½	—	—	2	14	65	99	1	9	21	73	—	2	—	—	1	1	—	—	288
5¾	—	1	2	12	70	55	—	13	29	59	—	2	—	—	—	2	—	—	245
6	—	—	—	14	84	30	4	10	35	61	1	3	—	—	—	2	—	—	244
6¼	1	1	1	3	46	16	3	11	37	39	1	3	—	—	1	1	—	1	165
6½	—	—	8	5	70	3	5	14	47	36	3	7	—	—	2	3	—	—	203
6¾	—	—	8	2	39	3	4	12	44	22	3	10	—	—	1	2	—	—	150
7	—	—	5	—	23	1	8	10	43	14	5	8	—	—	1	1	—	—	119
7¼	—	—	6	—	22	—	10	10	26	13	9	8	—	—	—	2	—	—	106
7½	—	—	8	2	10	1	8	11	40	4	13	11	—	—	1	—	—	—	109
7¾	—	—	6	—	2	—	9	10	17	—	19	7	—	—	—	1	—	—	71
8	—	—	4	1	2	—	11	4	20	—	13	14	—	—	—	—	1	—	70
8¼	—	—	5	—	—	—	10	—	5	—	18	5	—	—	—	—	—	—	43
8½	—	—	6	—	—	—	13	1	7	—	30	11	—	—	—	—	—	—	68
8¾	—	—	5	—	—	—	5	3	1	—	27	7	—	—	—	—	—	—	48
9	—	—	2	—	—	—	6	—	1	—	22	4	—	—	1	—	—	—	36
9¼	—	—	—	—	—	—	5	—	1	—	24	3	—	—	—	—	—	—	33
9½	—	—	—	—	—	—	5	—	—	—	20	4	—	—	—	—	—	—	29
9¾	—	—	1	—	—	—	2	—	—	—	16	1	—	—	—	—	—	—	20
10	—	—	—	—	—	—	3	—	—	—	10	—	—	—	—	—	—	—	13
10¼	—	—	—	—	—	—	—	—	—	—	15	—	1	—	—	—	—	—	16
10½	—	—	—	—	—	—	—	—	—	—	7	—	—	—	—	—	—	—	7
10¾	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
11	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	3
11¼	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1
11½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
11¾	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1
12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
12¼	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
12½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
12¾	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
13	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
13¼	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
13½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
13¾	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Totals	7	3	71	80	527	613	113	126	391	464	261	111	1	—	8	15	1	1	2,793
Average weights	4.5	5.5	7.4	5.6	6.0	5.2	7.9	6.6	6.7	5.7	8.8	7.6	10.3	—	6.9	6.5	7.9	6.3	6.3

Table IV.—Nass River Sockeyes, Average Lengths in Inches of Principal Age-groups, 1912 to 1951

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1912–41	24.5	23.7	26.3	25.2	26.1	25.3	27.7	26.4
1912–41 (conversion)	23.8	23.0	25.6	24.5	25.4	24.6	27.0	25.7
1942	23.9	23.2	26.1	24.9	24.9	24.3	26.9	26.0
1943	22.8	22.2	26.1	24.8	24.1	23.5	27.1	25.8
1944	23.5	22.7	25.7	24.6	24.8	23.8	26.8	25.8
1945	23.4	22.8	25.0	24.4	24.7	24.0	25.1	25.5
1946	23.4	22.4	26.3	24.9	24.9	23.9	28.1	26.0
1947	23.4	22.9	25.9	24.1	24.5	23.6	27.0	25.6
1948	23.3	22.6	26.2	25.3	25.0	24.1	27.7	26.7
1949	23.8	22.8	26.2	23.8	24.7	23.7	26.1	25.5
1950	23.6	23.1	26.0	24.7	24.5	23.7	26.7	25.6
1951	24.0	23.1	26.2	24.8	25.1	24.1	27.4	26.4

Table V.—Nass River Sockeyes, Average Weights in Pounds of Principal Age-groups, 1914 to 1951

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1914–41	6.0	5.4	7.3	6.4	6.9	6.2	8.0	7.0
1942	5.8	5.1	7.1	6.3	6.2	5.6	7.5	6.7
1943	5.2	4.7	7.6	6.4	5.9	5.3	7.9	6.9
1944	5.7	5.0	7.7	6.5	6.7	5.7	8.2	7.1
1945	5.7	5.3	7.0	6.4	6.5	5.9	7.2	7.1
1946	5.6	4.9	8.1	6.7	6.5	5.4	8.9	7.0
1947	5.8	5.3	7.7	6.2	6.3	5.6	8.1	6.9
1948	5.8	5.3	8.1	7.1	7.0	6.0	9.1	7.9
1949	5.9	5.1	7.9	5.8	6.5	5.4	7.7	6.8
1950	5.9	5.2	7.9	6.6	6.4	5.5	8.2	7.1
1951	6.0	5.2	7.9	6.6	6.7	5.7	8.8	7.6

Table VI.—Nass River Sockeyes, Percentages of Males and Females, 1915 to 1951

Year	4_2		5_2		5_3		6_3		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.	M.	F.		
1915–41 (average)	49	51	47	53	45	55	63	37	47	53
1942	42	58	48	52	44	56	70	30	45	55
1943	51	49	67	33	47	53	74	26	54	46
1944	53	47	45	55	39	61	60	40	50	50
1945	37	63	37	63	38	62	53	47	38	62
1946	62	38	59	41	45	55	75	25	50	50
1947	50	50	52	48	51	49	81	19	56	44
1948	45	55	54	46	52	48	66	34	53	47
1949	57	43	56	44	51	49	50	50	53	47
1950	41	59	42	58	43	57	58	42	44	56
1951	46	54	47	53	46	54	70	30	49	51

Table VII.—Skeena River Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Percentage of Individuals			
	4_2	5_2	5_3	6_3
1907 (108,413 cases)	—	—	—	—
1908 (139,846 cases)	—	—	—	—
1909 (87,901 cases)	—	—	—	—
1910 (187,246 cases)	—	—	—	—
1911 (131,066 cases)	—	—	—	—
1912 (92,498 cases)	57	43	—	—
1913 (52,927 cases)	50	50	—	—
1914 (130,166 cases)	25	75	—	—
1915 (116,553 cases)	36	64	—	—
1916 (60,923 cases)	34	38	13	18
1917 (65,760 cases)	57	29	9	5
1918 (123,322 cases)	51	34	9	6
1919 (184,945 cases)	27	60	9	4
1920 (90,869 cases)	15	71	6	8
1921 (41,018 cases)	69	22	6	3
1922 (96,277 cases)	70	16	12	2
1923 (131,731 cases)	56	29	8	7
1924 (144,747 cases)	23	69	7	1
1925 (77,784 cases)	51	45	3	1
1926 (82,360 cases)	62	26	9	3
1927 (83,996 cases)	62	28	9	1
1928 (34,559 cases)	51	39	7	3
1929 (78,017 cases)	62	30	6	2
1930 (132,372 cases)	39	52	8	1
1931 (93,023 cases)	40	30	28	2
1932 (59,916 cases)	44	37	7	12
1933 (30,506 cases)	57	36	5	2
1934 (54,558 cases)	58	34	7	1
1935 (52,879 cases)	49	31	18	2
1936 (81,973 cases)	67	20	11	2
1937 (42,491 cases)	45	40	11	4
1938 (47,257 cases)	64	15	16	5
1939 (68,485 cases)	50	35	11	4
1940 (116,507 cases)	80	15	4	1
1941 (81,767 cases)	39	52	8	1
1942 (34,544 cases)	36	54	7	3
1943 (28,268 cases)	39	39	16	6
1944 (68,197 cases)	37	52	7	4
1945 (104,279 cases)	20	63	12	5
1946 (52,928 cases)	13	70	8	9
1947 (32,534 cases)	14	82	3	1
1948 (101,267 cases)	80	13	6	1
1949 (65,937 cases)	17	76	4	3
1950 (47,479 cases)	21	72	4	3
1951 (61,694 cases)	33	61	4	1

Table VIII.—Skeena River Sockeyes, 1951, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals																				
	3_1		4_1		3_2		4_2		5_2		6_2		4_3		5_3		6_3		6_4		Total
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
14																					
14¼																					
14½																					
14¾																					
15																					
15¼																					
15½																					
15¾																					
16					1								1								2
16¼																					
16½																					
16¾																					
17					1																1
17¼					1																1
17½					1																1
17¾																					
18																					
18¼																					
18½																					
18¾																					
19																					
19¼																					
19½							1														1
19¾																					
20	1						3														4
20¼							3														3
20½							4														4
20¾							9	2													11
21							19	6													25
21¼							23	12							1	1					37
21½							20	23		1					1	1					46
21¾							20	29		1					1	1					52
22							20	65		1					1	3					90
22¼							27	67	2	2				1		6					105
22½							23	102	3	5					5	11					149
22¾							29	83	3	7					2	11					135
23				1			49	69		10					5	7					141
23¼							23	43	2	24					11	6		1			110
23½							34	39	4	43					14	5		1	1		141
23¾							12	18	4	60					7	3					104
24							29	10	11	85					6	2	1	4			148
24¼							20	1	12	130					5	2		3			173
24½							11	4	27	121					4		3	3			173
24¾							4		20	120					1						145
25							3	1	41	165					1		2	1			214
25¼							4		56	100		1			1	1	2	2		1	168
25½							2		62	94					2	1		1			162
25¾							1		54	60							1	1			117
26								1	96	65							1				163
26¼									65	30											95
26½									64	13							5	1			83
26¾									42	11							3				56
27									49	4											53
27¼									28	2											30
27½									15												15
27¾									9						1						10
28									1	1							1				3
28¼									6												6
28½																					
28¾																	1				1
29																					
29¼																					
Totals	1			1	4		393	575	676	1,155		1	1	1	69	61	20	18	1	1	2,978
Average lengths	20.0			23.0	16.9		22.7	22.6	25.9	24.8		25.3	16.0	22.3	23.6	22.9	26.0	24.6	23.5	25.3	24.3

Table IX.—Skeena River Sockeyes, 1951, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals																				Total
	3_1		4_1		3_2		4_2		5_2		6_2		4_3		5_3		6_3		6_4		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
1																					
1¼																					
1½																					
1¾					1								1								2
2					1																1
2¼					1																1
2½					1																1
2¾																					
3																					
3¼							2	1													3
3½							4														4
3¾							17	2													19
4	1						30	14		1					2	2					50
4¼							32	42		2					1	5					82
4½							51	127	1	10					5	15					209
4¾							44	105	2	16					4	8		1			180
5							32	102	7	29					6	12					188
5¼				1			36	64	4	37				1	8	4				1	156
5½							48	65	14	87					16	9	1	2			242
5¾							31	25	11	124					9	2		2			204
6							15	14	26	116		1			10		2	3		1	188
6¼							16	7	18	114					3	2	1				161
6½							12	3	38	165					1	2	1	5			227
6¾							9	2	40	99					1		3				154
7							4		61	92								1			158
7¼							3		50	67								1			121
7½							3	1	84	77					1		1	1			168
7¾							3		70	39					1		4	1			118
8								1	49	22							3	1			76
8¼									38	25											63
8½							1		55	25							2				83
8¾									40	3											43
9									25	3											28
9¼									10						1						11
9½									15												15
9¾									8	1											9
10									4								1				5
10¼									1												1
10½									2												2
10¾									2	1											3
11																					
11¼																					
11½									1								1				2
11¾																					
12																					
12¼																					
12½																					
12¾																					
13																					
13¼																					
13½																					
13¾																					
Totals	1			1	4		393	575	676	1,155		1	1	1	69	61	20	18	1	1	2,978
Average weights	4.0			5.2	2.1		5.1	5.0	7.6	6.5			1.7	5.2	5.6	5.0	7.6	6.4	5.3	6.0	6.2

Table X.—Skeena River Sockeyes, Average Lengths in Inches of Principal Age-groups, 1912 to 1951

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1912–41	23.7	23.1	25.8	24.9	24.2	23.4	25.8	24.8
1912–41 (conversion)	23.0	22.4	25.1	24.2	23.5	22.7	25.1	24.1
1942	22.6	22.3	25.2	24.3	24.1	23.7	26.3	24.9
1943	21.9	21.9	25.1	23.9	23.3	22.6	25.8	24.7
1944	22.4	21.7	24.8	23.9	22.5	21.7	25.0	23.7
1945	22.6	22.3	24.9	24.1	23.3	22.6	25.0	24.3
1946	22.7	22.0	25.4	24.3	23.9	23.2	25.5	24.4
1947	22.3	22.0	25.1	23.8	23.0	22.4	26.3	25.8
1948	23.0	22.3	25.3	24.1	23.0	22.1	26.0	24.5
1949	22.5	22.2	25.3	24.5	23.2	22.3	24.8	23.9
1950	22.8	22.3	25.7	24.4	23.9	23.4	25.5	24.3
1951	22.7	22.6	25.9	24.8	23.6	22.9	26.0	24.6

Table XI.—Skeena River Sockeyes, Average Weights in Pounds of Principal Age-groups, 1914 to 1951

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1914–41	5.4	5.0	6.8	6.1	5.7	5.1	6.8	6.0
1942	4.9	4.7	6.7	6.0	5.8	5.4	7.2	6.6
1943	4.7	4.6	6.8	5.9	5.5	4.9	7.3	6.1
1944	5.1	4.6	7.0	6.1	5.3	4.6	7.1	5.8
1945	5.2	4.9	6.7	6.1	5.6	5.0	6.7	6.2
1946	4.7	4.2	6.9	5.8	5.8	5.1	7.0	6.1
1947	4.9	4.7	6.9	5.9	5.3	5.0	7.7	6.8
1948	5.5	4.9	7.3	6.1	5.4	4.7	7.7	6.4
1949	5.0	4.7	7.1	6.3	5.3	4.8	6.6	5.7
1950	4.8	4.3	7.2	5.9	5.8	5.1	6.8	5.6
1951	5.1	5.0	7.6	6.5	5.6	5.0	7.6	6.4

Table XII.—Skeena River Sockeyes, Percentages of Males and Females, 1915 to 1951

Year	4_2		5_2		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.		
1915–41 (average)	48	52	43	57	46	54
1942	42	58	25	75	33	67
1943	50	50	31	69	43	57
1944	54	46	34	66	43	57
1945	41	59	35	65	38	62
1946	50	50	32	68	38	62
1947	50	50	29	71	33	67
1948	50	50	29	71	47	53
1949	54	46	30	70	36	64
1950	56	44	40	60	44	56
1951	41	59	37	63	39	61

Table XIII.—Rivers Inlet Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Percentage of Individuals			
	4_2	5_2	5_3	6_3
1907 (87,874 cases)	—	—	—	—
1908 (64,652 cases)	—	—	—	—
1909 (89,027 cases)	—	—	—	—
1910 (126,921 cases)	—	—	—	—
1911 (88,763 cases)	—	—	—	—
1912 (112,884 cases)	21	79	—	—
1913 (61,745 cases)	80	20	—	—
1914 (89,890 cases)	35	65	—	—
1915 (130,350 cases)	13	87	—	—
1916 (44,936 cases)	26	74	—	—
1917 (61,195 cases)	39	61	—	—
1918 (53,401 cases)	57	43	—	—
1919 (56,258 cases)	46	54	—	—
1920 (121,254 cases)	5	95	—	—
1921 (46,300 cases)	49	51	—	—
1922 (60,700 cases)	81	18	1	—
1923 (107,174 cases)	74	24	2	—
1924 (94,891 cases)	43	54	2	1
1925 (159,554 cases)	23	77	—	—
1926 (65,581 cases)	59	38	2	1
1927 (64,461 cases)	81	16	3	—
1928 (60,044 cases)	55	40	4	1
1929 (70,260 cases)	77	18	3	2
1930 (119,170 cases)	49	48	2	1
1931 (76,428 cases)	53	44	2	1
1932 (69,732 cases)	67	27	5	1
1933 (83,507 cases)	44	55	1	—
1934 (76,923 cases)	77	20	2	1
1935 (135,038 cases)	57	41	1	1
1936 (46,351 cases)	53	46	1	—
1937 (84,832 cases)	60	37	3	—
1938 (87,942 cases)	27	70	1	2
1939 (54,143 cases)	67	32	1	—
1940 (63,469 cases)	69	28	3	—
1941 (93,378 cases)	59	40	1	—
1942 (79,199 cases)	8	91	—	1
1943 (47,602 cases)	8	91	—	1
1944 (36,852 cases)	76	23	1	—
1945 (89,735 cases)	57	41	2	—
1946 (73,320 cases)	37	63	—	—
1947 (140,087 cases)	3	97	—	—
1948 (37,665 cases)	55	44	1	—
1949 (39,495 cases)	84	14	1	—
1950 (142,710 cases)	13	87	(1)	—
1951 (102,565 cases)	38	60	1	1

[1] Age-class represented but less than 0.5 per cent.

Table XIV.—Rivers Inlet Sockeyes, 1951, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals																Total
	4_1		3_2		4_2		5_2		6_2		5_3		6_3		5_4		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
14																	
14¼																	
14½																	
14¾																	
15			1														1
15¼			1														1
15½																	
15¾																	
16			1														1
16¼																	
16½																	
16¾																	
17																	
17¼			1														1
17½																	
17¾																	
18																	
18¼																	
18½																	
18¾																	
19					1												1
19¼					6												6
19½					7	1											8
19¾					13	3											16
20					11	2											13
20¼					17	9											26
20½					16	6					2						24
20¾					23	9											32
21					29	22											51
21¼					22	13	1	1				1					38
21½					33	17		1									51
21¾					21	16	1					1					39
22					17	14		1									32
22¼					11	11		3									25
22½					22	11	1	9									43
22¾					10	19	2	6			1	1					39
23					18	10	9	16				1					54
23¼					15	6	8	24									53
23½					16	5	6	19				1					47
23¾		1			9	7	5	28				2					52
24					7	2	7	20				1			1		38
24¼					12	1	7	36			1						57
24½					7	1	7	58						1			74
24¾					3		6	61			1						71
25					3		9	67			1	1					81
25¼							12	58			1	1					72
25½					2		12	54						1			69
25¾					3		18	42					1	2			66
26							26	27						2			55
26¼							17	30						1			48
26½							20	19									39
26¾							19	6		1							26
27							19	3									22
27¼							13	1									14
27½							10	1					1				12
27¾							7	1									8
28							8										8
28¼							1										1
28½							2										2
28¾							1										1
29																	
29¼																	
29½							2										2
Totals		1	4		354	185	256	592		1	7	10	2	7	1		1,420
Average lengths		23.8	15.9		21.9	21.9	25.8	24.8		26.8	23.3	23.4	26.6	25.7	24.0		23.9

Table XV.—Rivers Inlet Sockeyes, 1951, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals																Total
	4_1		3_2		4_2		5_2		6_2		5_3		6_3		5_4		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
1																	
1¼																	
1½																	
1¾			2														2
2			1														1
2¼			1														1
2½					1												1
2¾																	
3					3	2											5
3¼					5												5
3½					5	2											7
3¾					12	3		3									18
4					30	11	1	1			1	1					45
4¼					34	13	1										48
4½					43	31		3			2	1					80
4¾					28	21	2	4				1					56
5					37	24	1	5									67
5¼					17	15	2	5				1					40
5½					20	23	3	19				2					67
5¾					16	17	1	12									46
6		1			22	9	11	28			1				1		73
6¼					15	4	9	24				1					53
6½					20	5	6	32				1					64
6¾					9	3	9	33									54
7					15	2	4	58									79
7¼					6		8	41			2			1			58
7½					6		9	67			1	2	1				86
7¾					1		13	42									56
8					8		12	57						1			78
8¼					1		12	31									44
8½							23	43						1			67
8¾							13	28						2			43
9							19	24					1	2			46
9¼							15	10									25
9½							20	17									37
9¾							12	1		1							14
10							8										8
10¼							8	1									9
10½							11	1									12
10¾							6	1									7
11							5	1									6
11¼							1										1
11½							5										5
11¾							2										2
12							1										1
12¼							1										1
12½							1										1
12¾																	
13																	
13¼							1										1
13½																	
13¾																	
Totals		1	4		354	185	256	592		1	7	10	2	7	1		1,420
Average weights		6.0	2.0		5.2	5.0	8.6	7.4		9.7	5.8	5.7	8.3	8.5	6.0		6.7

Table XVI.—Rivers Inlet Sockeyes, Average Lengths in Inches of the 4_2 and 5_2 Groups, 1912 to 1951

Year	4_2		5_2	
	M.	F.	M.	F.
1912–41	22.4	22.4	25.4	24.7
1912–41 (conversion)	21.6	21.6	24.6	23.9
1942	21.9	21.3	25.0	23.8
1943	20.5	21.1	24.3	23.7
1944	21.1	21.0	23.5	23.3
1945	20.9	21.2	24.2	23.9
1946	20.6	21.1	25.1	24.1
1947	20.6	20.7	24.0	23.5
1948	21.4	21.3	25.2	24.2
1949	20.9	21.4	23.8	22.8
1950	21.1	20.8	25.2	24.2
1951	21.9	21.9	25.8	24.8

Table XVII.—Rivers Inlet Sockeyes, Average Weights in Pounds of the 4_2 and 5_2 Groups, 1914 to 1951

Year	4_2		5_2	
	M.	F.	M.	F.
1914–41	4.9	4.8	7.0	6.5
1942	5.1	4.6	7.2	6.4
1943	4.1	4.4	6.8	6.3
1944	4.6	4.4	6.2	6.0
1945	4.3	4.4	6.6	6.4
1946	3.9	3.9	7.2	6.2
1947	4.1	3.9	6.4	5.9
1948	4.7	4.6	7.9	7.0
1949	4.4	4.3	5.9	5.9
1950	4.2	3.9	7.5	6.4
1951	5.2	5.0	8.6	7.4

Table XVIII.—Rivers Inlet Sockeyes, Percentages of Males and Females, 1915 to 1951

Year	4_1		4_2		5_2		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.		
1915–41 (average)			63	37	34	66	50	50
1942			61	39	35	65	38	62
1943			62	38	34	66	36	64
1944			67	33	33	67	59	41
1945			70	30	39	61	57	43
1946			79	21	37	63	53	47
1947			72	28	35	65	36	64
1948			50	50	38	62	45	55
1949	36	64	70	30	22	78	63	37
1950	50	50	75	25	36	64	41	59
1951			66	34	30	70	44	56

Table XIX.—Smith Inlet Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Percentage of Individuals				
	4_1	4_2	5_2	6_2	5_3
1925 (33,764 cases)	—	—	—	—	—
1926 (17,921 cases)	—	—	—	—	—
1927 (22,682 cases)	—	—	—	—	—
1928 (33,442 cases)	—	—	—	—	—
1929 (9,683 cases)	—	—	—	—	—
1930 (32,057 cases)	—	—	—	—	—
1931 (12,867 cases)	—	—	—	—	—
1932 (25,488 cases)	—	—	—	—	—
1933 (37,369 cases)	—	—	—	—	—
1934 (14,607 cases)	—	—	—	—	—
1935 (31,648 cases)	—	—	—	—	—
1936 (12,788 cases)	—	—	—	—	—
1937 (25,258 cases)	—	—	—	—	—
1938 (33,894 cases)	—	—	—	—	—
1939 (17,833 cases)	—	—	—	—	—
1940 (25,947 cases)	—	—	—	—	—
1941 (21,495 cases)	—	—	—	—	—
1942 (15,939 cases)	—	—	—	—	—
1943 (15,010 cases)	—	—	—	—	—
1944 (3,165 cases)	—	—	—	—	—
1945 (15,014 cases)	—	50	50	—	—
1946 (14,318 cases)	—	11	89	—	—
1947 (36,800 cases)	—	5	95	—	—
1948 (10,456 cases)	—	7	90	3	—
1949 (13,189 cases)	2	92	5	—	(1)
1950 (42,435 cases)	—	17	83	—	(1)
1951 (49,473 cases)	—	22	77	(1)	(1)

[1] This age-class was represented by less than 0.5 per cent of the number of fish in the sample.

Table XX.—Smith Inlet Sockeyes, 1951, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals										Total
	3_2		4_2		5_2		6_2		5_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
14	—	—	—	—	—	—	—	—	—	—	—
14¼	—	—	—	—	—	—	—	—	—	—	—
14½	—	—	—	—	—	—	—	—	—	—	—
14¾	—	—	—	—	—	—	—	—	—	—	—
15	—	—	—	—	—	—	—	—	—	—	—
15¼	—	—	—	—	—	—	—	—	—	—	—
15½	—	—	—	—	—	—	—	—	—	—	—
15¾	—	—	—	—	—	—	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—	—	—
16¼	—	—	—	—	—	—	—	—	—	—	—
16½	—	—	—	—	—	—	—	—	—	—	—
16¾	—	—	—	—	—	—	—	—	—	—	—
17	—	—	—	—	—	—	—	—	—	—	—
17¼	—	—	—	—	—	—	—	—	—	—	—
17½	—	—	—	—	—	—	—	—	—	—	—
17¾	—	—	—	—	—	—	—	—	—	—	—
18	—	—	—	—	—	—	—	—	—	—	—
18¼	—	—	—	—	—	—	—	—	—	—	—
18½	—	—	—	—	—	—	—	—	—	—	—
18¾	—	—	—	—	—	—	—	—	—	—	—
19	—	—	—	—	—	—	—	—	—	—	—
19¼	—	—	—	—	—	—	—	—	—	—	—
19½	1	—	—	—	—	—	—	—	—	—	1
19¾	—	—	—	—	1	—	—	—	—	—	1
20	—	—	—	—	—	—	—	—	—	—	—
20¼	—	—	—	—	—	—	—	—	—	—	—
20½	—	—	—	1	—	—	—	—	—	—	1
20¾	—	—	—	1	—	—	—	—	—	—	1
21	—	—	3	2	—	—	—	—	—	—	5
21¼	—	—	2	1	—	—	—	—	—	—	3
21½	—	—	6	12	—	—	—	—	—	—	18
21¾	—	—	6	5	1	—	—	—	—	—	12
22	—	—	7	5	—	—	—	—	—	—	12
22¼	—	—	8	2	—	1	—	—	—	—	11
22½	—	—	12	2	1	—	—	—	—	—	15
22¾	—	—	7	2	—	1	—	—	1	—	11
23	—	—	20	6	4	2	—	—	—	—	32
23¼	—	—	8	1	—	3	—	—	—	—	12
23½	—	—	12	—	1	19	—	—	—	—	32
23¾	—	—	7	1	5	9	—	—	—	—	22
24	—	—	2	—	3	24	—	—	1	—	30
24¼	—	—	3	—	4	16	—	—	—	—	23
24½	—	—	2	—	11	55	—	—	—	—	68
24¾	—	—	1	—	7	28	—	—	—	—	36
25	—	—	—	—	22	46	—	2	—	—	70
25¼	—	—	—	—	16	36	—	—	—	—	52
25½	—	—	—	—	29	34	—	—	—	—	63
25¾	—	—	—	—	16	13	—	—	—	—	29
26	—	—	—	—	32	11	—	—	—	—	43
26¼	—	—	—	—	14	1	—	—	—	—	15
26½	—	—	—	—	22	6	—	—	—	—	28
26¾	—	—	—	—	9	—	—	—	—	—	9
27	—	—	—	—	9	—	—	—	—	—	9
27¼	—	—	—	—	5	—	—	—	—	—	5
27½	—	—	—	—	2	—	—	—	—	—	2
27¾	—	—	—	—	1	—	—	—	—	—	1
28	—	—	—	—	—	—	—	—	—	—	—
28¼	—	—	—	—	1	—	—	—	—	—	1
28½	—	—	—	—	—	—	—	—	—	—	—
28¾	—	—	—	—	—	—	—	—	—	—	—
29	—	—	—	—	—	—	—	—	—	—	—
29¼	—	—	—	—	—	—	—	—	—	—	—
Totals	1	—	106	41	216	305		2	2		673
Average lengths	19.5		22.8	22.0	25.6	24.8		25.1	23.4		24.5

Table XXI.—Smith Inlet Sockeyes, 1951, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals										Total
	3_2		4_2		5_2		6_2		5_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
1	—	—	—	—	—	—	—	—	—	—	—
1¼	—	—	—	—	—	—	—	—	—	—	—
1½	—	—	—	—	—	—	—	—	—	—	—
1¾	—	—	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	—	—	—	—	—
2¼	—	—	—	—	—	—	—	—	—	—	—
2½	—	—	—	—	—	—	—	—	—	—	—
2¾	—	—	—	—	—	—	—	—	—	—	—
3	—	—	—	—	—	—	—	—	—	—	—
3¼	—	—	—	—	—	—	—	—	—	—	—
3½	1	—	—	—	—	—	—	—	—	—	1
3¾	—	—	—	—	—	—	—	—	—	—	—
4	—	—	—	—	—	—	—	—	—	—	—
4¼	—	—	—	—	—	—	—	—	—	—	—
4½	—	—	3	8	—	—	—	—	—	—	11
4¾	—	—	3	5	2	—	—	—	—	—	10
5	—	—	11	10	1	1	—	—	—	—	23
5¼	—	—	6	2	—	2	—	—	—	—	10
5½	—	—	17	7	2	2	—	—	1	—	29
5¾	—	—	13	5	1	6	—	—	—	—	25
6	—	—	15	3	3	14	—	—	—	—	35
6¼	—	—	11	1	4	10	—	—	—	—	26
6½	—	—	10	—	6	36	—	—	—	—	52
6¾	—	—	8	—	5	17	—	—	—	—	30
7	—	—	2	—	8	43	—	1	—	—	54
7¼	—	—	2	—	8	30	—	—	1	—	41
7½	—	—	2	—	28	45	—	1	—	—	76
7¾	—	—	1	—	11	28	—	—	—	—	40
8	—	—	1	—	29	31	—	—	—	—	61
8¼	—	—	—	—	14	11	—	—	—	—	25
8½	—	—	—	—	19	18	—	—	—	—	37
8¾	—	—	1	—	10	6	—	—	—	—	17
9	—	—	—	—	24	3	—	—	—	—	27
9¼	—	—	—	—	10	2	—	—	—	—	12
9½	—	—	—	—	9	—	—	—	—	—	9
9¾	—	—	—	—	5	—	—	—	—	—	5
10	—	—	—	—	7	—	—	—	—	—	7
10¼	—	—	—	—	4	—	—	—	—	—	4
10½	—	—	—	—	3	—	—	—	—	—	3
10¾	—	—	—	—	—	—	—	—	—	—	—
11	—	—	—	—	1	—	—	—	—	—	1
11¼	—	—	—	—	—	—	—	—	—	—	—
11½	—	—	—	—	2	—	—	—	—	—	2
11¾	—	—	—	—	—	—	—	—	—	—	—
12	—	—	—	—	—	—	—	—	—	—	—
12¼	—	—	—	—	—	—	—	—	—	—	—
12½	—	—	—	—	—	—	—	—	—	—	—
12¾	—	—	—	—	—	—	—	—	—	—	—
13	—	—	—	—	—	—	—	—	—	—	—
13¼	—	—	—	—	—	—	—	—	—	—	—
13½	—	—	—	—	—	—	—	—	—	—	—
13¾	—	—	—	—	—	—	—	—	—	—	—
Totals	1	—	106	41	216	305	—	2	2	—	673
Average weights	3.6	—	6.0	5.2	8.2	7.3	—	7.2	6.4	—	7.2

Table XXII.—Smith Inlet Sockeyes, Average Lengths in Inches of Age-groups, 1945 to 1951

Year	4_1		4_2		5_2		6_2		5_3	
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.
1945			22.2	22.0	25.1	24.4				
1946			21.3	22.7	24.7	24.0				
1947			23.2	23.4	25.2	24.3				
1948			21.9	21.7	25.0	24.3	26.7	25.0		
1949	25.4	23.5	21.4	21.7	24.6	24.3		25.5		
1950			21.6	21.7	24.8	24.0			20.5	
1951			22.8	22.0	25.6	24.8		25.1	23.4	

Table XXIII.—Smith Inlet Sockeyes, Average Weights in Pounds of Age-groups, 1945 to 1951

Year	4_1		4_2		5_2		6_2		5_3	
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.
1945			4.9	4.7	7.1	6.5				
1946			4.6	5.8	7.3	6.6				
1947			5.7	5.5	6.9	6.0				
1948			5.1	5.4	7.6	6.9	10.3	7.5		
1949	7.9	6.1	5.0	5.1	7.2	6.7		7.3		
1950			4.9	5.0	7.4	6.6			4.0	
1951			6.0	5.2	8.2	7.3		7.2	6.4	

Table XXIV.—Smith Inlet Sockeyes, Percentages of Males and Females, 1945 to 1951

Year	4_1		4_2		5_2		6_2		5_3		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.		
1945			73	27	49	51					61	39
1946			76	24	37	63					41	59
1947		—	38	62	47	53	—	—	—	—	46	54
1948		—	79	21	42	58	11	89	—	—	43	57
1949	36	64	80	20	40	60	—	100	—	—	77	23
1950		—	86	14	42	58	—	—	100	—	49	51
1951	—	—	72	28	41	59	—	100	100	—	48	52

Table XXV.—Length Distribution of Spawning-ground Samples, Rivers Inlet Sockeye

Length in Inches	Males	Females	Total	Length in Inches	Males	Females	Total
13	1	—	1	21¼	—	—	—
13¼	—	—	—	21½	—	1	1
13½	1	—	1	21¾	—	—	—
13¾	—	—	—	22	—	3	3
14	7	—	7	22¼	1	—	1
14¼	1	—	1	22½	—	3	3
14½	7	—	7	22¾	—	—	—
14¾	—	—	—	23	1	1	2
15	1	—	1	23¼	—	1	1
15¼	1	—	1	23½	—	3	3
15½	2	—	2	23¾	—	—	—
15¾	—	—	—	24	2	3	5
16	—	—	—	24¼	—	—	—
16¼	—	—	—	24½	1	5	6
16½	1	—	1	24¾	1	—	1
16¾	—	—	—	25	—	17	17
17	—	—	—	25¼	—	1	1
17¼	—	—	—	25½	4	18	22
17½	—	—	—	25¾	—	—	—
17¾	—	—	—	26	1	10	11
18	—	—	—	26¼	—	—	—
18¼	—	—	—	26½	3	2	5
18½	3	—	3	26¾	—	—	—
18¾	1	—	1	27	2	—	2
19	2	—	2	27¼	1	—	1
19¼	—	—	—	27½	9	1	10
19½	3	—	3	27¾	—	—	—
19¾	—	—	—	28	7	—	7
20	4	—	4	28¼	—	—	—
20¼	—	—	—	28½	5	—	5
20½	1	1	2	28¾	—	—	—
20¾	—	—	—	29	2	—	2
21	—	3	3	Totals	76	73	149

VICTORIA, B.C.
Printed by DON MCDIARMID, Printer to the Queen's Most Excellent Majesty
1953

1,100-1252 9034

RESULTS OF THE WEST COAST OF VANCOUVER ISLAND HERRING INVESTIGATION, 1951–52

By J. C. Stevenson, M.A.; A. S. Hourston, M.A.; K. J. Jackson, B.A.; and D. N. Outram, B.A., Pacific Biological Station, Nanaimo, B.C.

CONTENTS

	Page
Introduction	57
The 1951–52 Fishery	58
Tagging and Tag-recovery	63
Recoveries by Tag-detectors	65
Movement between Populations	65
Movement within Populations	67
Recovery of Tags by Plant Crews	68
Tagging during the 1952 Spawning Season	70
Sampling of the Catches and the Spawning Runs	70
Age Composition	71
Sex Ratio and Stage of Development	73
Average Length and Weight	73
Extent and Intensity of Spawning	74
Discussion	76
Summary	79
Acknowledgments	80
References	81
Tables	82

INTRODUCTION

Since 1946–47 the herring population of the west coast of Vancouver Island has been fished without any limitations to catch except for a closure date prior to spawning. During the same period the herring-catch on the lower east coast of Vancouver Island has been limited to 40,000 tons annually, and a similar closure date has been applied to fishing. The scientific investigation of these two herring populations over a number of years aims to determine the comparative merits of these two methods of fisheries management. More specifically, it seeks to find out whether catch quotas are effective in stabilizing herring populations in view of the great natural fluctuations which occur in abundance.

This report, the sixth in an annual series,* outlines the results of studies carried out on the adult stocks of the west coast of Vancouver Island population during the 1951–52 season, and in it these results are compared with those of previous seasons. As in previous reports, detailed consideration is given to changes in catch and fishing effort, to the year-classes which comprise the fishing and spawning runs, and to the relative amount of fish which escape the fishery. Also, the extent of movement between

* Previous publications in this series are Tester and Stevenson, 1947, 1948; Stevenson, 1950; Stevenson and Lanigan, 1950; and Stevenson, Hourston, and Lanigan, 1951.

all major herring populations, as determined by tag-recovery, is discussed. Finally, the results of the 1951–52 study are discussed from the point of view of their implications upon the comparative study of two populations subjected to different management methods.

Herring research on Pacific herring (*Clupea pallasi*) is undertaken by the Fisheries Research Board of Canada at the Pacific Biological Station, Nanaimo, B.C. It includes, besides the comparative study of two herring populations which forms the basis of this series of publications, various phases of research applied to all major fishable stocks. Also, investigation is continuing on certain aspects of the early life-history of the herring in an effort to understand more completely the principles involved in the supply of fish to the fishery, and thereby to acquire a sound basis for prediction of population abundance.

Districts, sub-districts, and areas in which British Columbia coastal waters are divided for purposes of fisheries statistics are shown in Fig. 1. Place-names along the coast of Vancouver Island and adjacent Mainland, which are mentioned in the text, are shown in Fig. 2.

THE 1951–52 FISHERY

The British Columbia herring-fishing season opened on November 15th, most boats seining in the middle east coast and lower east coast sub-districts. No fishing took place in the west coast of Vancouver Island sub-district until December 1st, when a fairly large body of herring was located in Effingham Inlet (Area 23). Fair fishing was experienced during the ensuing days, with from seven to eighteen boats participating, and almost 7,300 tons were caught. By December 8th seining proved unproductive, and most of the seiners, which had originally come around from the lower east coast, returned there or moved to the northern sub-district, where excellent catches were being made. From December 8th until fishing was closed for the Christmas recess on December 17th, fishing in the west coast sub-district was generally poor, partly because of the smaller fishing effort, but mainly because of the lack of sizable schools of fish to set on. The few boats which remained in the sub-district thoroughly scouted the fishing-grounds, and small bodies of fish were located in Effingham Inlet, in Barkley Sound (Area 23), in Clayoquot and Sydney Inlets (Area 24), and in Nootka, Tahsis, and Esperanza Inlets (Area 25). The total pre-Christmas catch on the west coast amounted to 8,900 tons. Barkley Sound accounted for the entire catch, except for about 300 tons from Nootka Sound taken during the last week of the fishery and 200 tons from Clayoquot Sound caught on December 17th.

Fishing recommenced on January 6th, when eleven boats seined in Barkley Sound. During the first four days approximately 2,200 tons were brailed from this area and 540 tons were taken from Sydney Inlet and Refuge Cove (Area 24). By January 10th the fish had scattered, and from then until the middle of the month small catches amounting to approximately 900 tons were made in all west coast areas except Area 27. The west coast fishery was non-existent after January 15th, when all boats left for the northern and central sub-districts, but a few of the boats returned after the completion of the quota extension in the northern sub-district on January 18th. All areas were scouted again, but without success. A time extension for fishing the more northerly west coast areas was sought and granted, the closure date being moved from February 5th to February 15th. On February 4th the herring started to move inshore to Esperanza Inlet (Area 25), and by the time the boats from the central sub-district arrived on February 8th, a vigorous fishery was in progress, reaching its peak on February 12th, when thirty-two boats seined over 4,000 tons on that day. Heavy fishing with high catch per unit of effort (101 tons per seine per day) continued until the closure on February 15th. The total west coast catch in 1951–52 was 30,000 tons (Table I), over one-half of which was taken during the time extension.

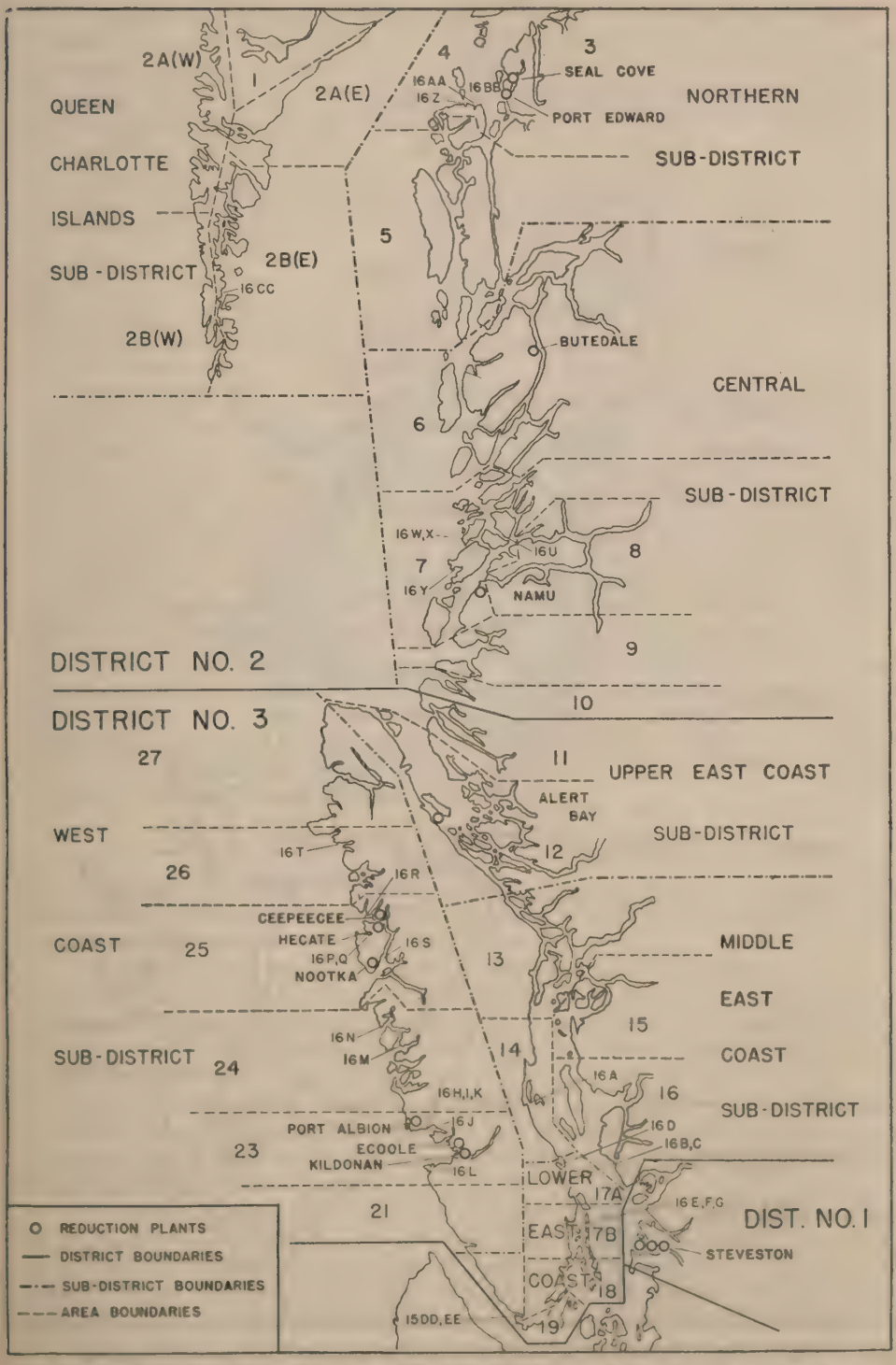


Fig. 1. Map showing the division of the British Columbia coast into districts, sub-districts, and areas, and including the locations and codes of taggings made during the fall of 1951 and the spring of 1952.

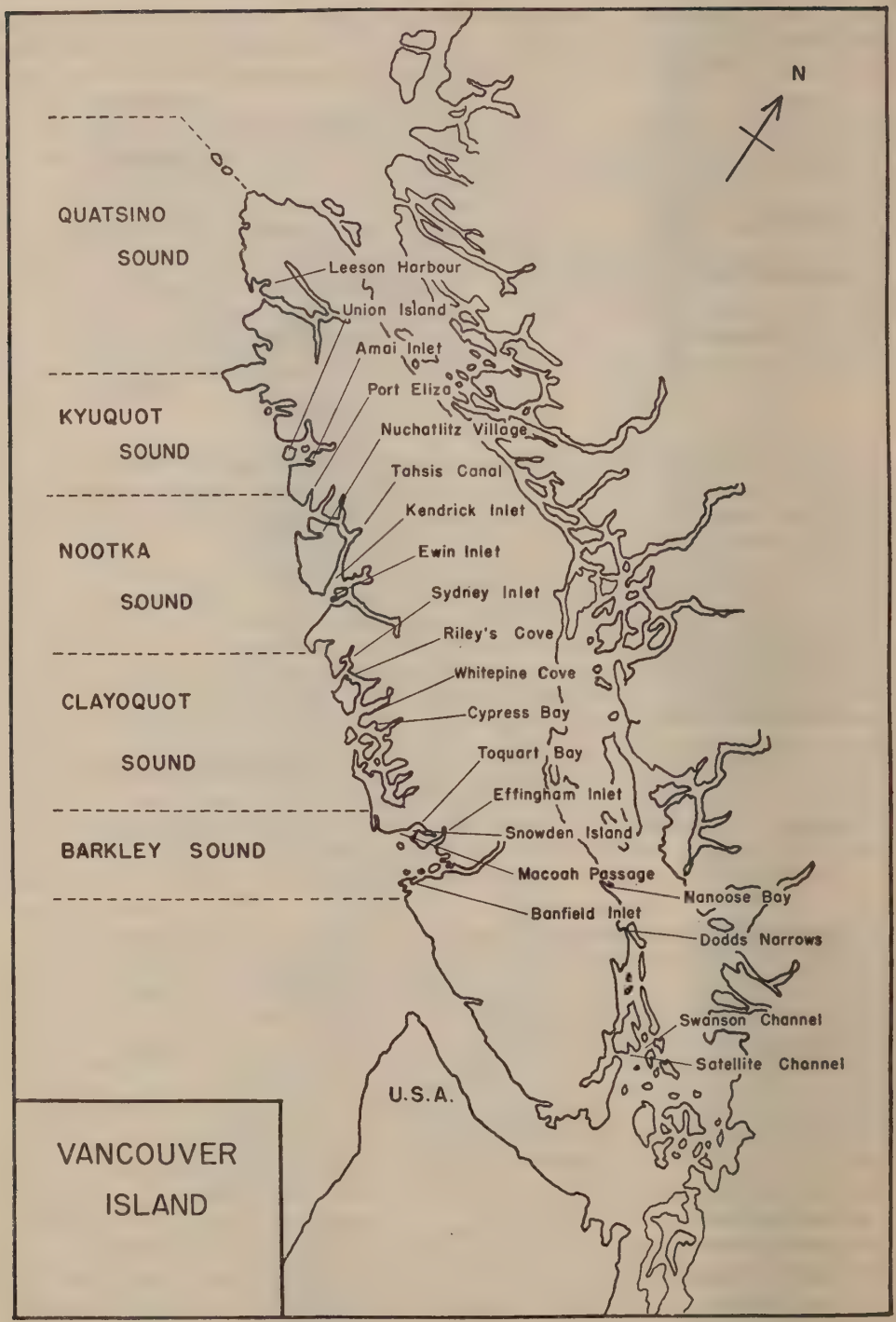


Fig. 2. Map of Southern British Columbia showing the location of some of the places mentioned in the text.

Details of catches, fishing effort, and catch per unit of effort are given for each area and the whole sub-district in Table I. Captains of seine-boats submitted data on the number of fishing or scouting days, and from these the catch per unit of effort was obtained. These records represented 75 per cent of the total catch for the sub-district, and the total fishing effort was gained by adjusting the number of recorded fishing-days to account for the whole catch.

Catch, fishing effort, and catch per unit of effort on the west coast of Vancouver Island are tabulated below for the 1951–52 and previous seasons:—

	1946–47	1947–48	1948–49	1949–50	1950–51	1951–52
Catch (tons)	59,000	45,200	55,000	37,300	25,200	30,000
Effort (seine-days)	777	948	686	790	528	395
Catch per unit of effort (tons per seine per day)	76	48	80	47	48	76

The 1951–52 west coast fishery produced the second smallest catch of the six-year period. The high average catch per unit of effort appears to be not comparable with availability figures of previous seasons, and is principally a result of the high catch per unit of effort in the Area 23 fishery—70.9 tons per seine per day (Table I), the highest availability for Area 23 in the six years of the study. Unusually great efficiency in fleet deployment during the period of fishing in Area 23 was undoubtedly a major factor in producing the artificially high availability. When fish were scarce on the fishing-grounds, the bulk of the fleet was moved promptly to fishing areas where fish were more plentiful. Spawning and age-composition data have strongly indicated that Area 23 stocks were smaller than at any time since the removal of quota restrictions.

The high availability of fish in Area 25 (Table I) was partly the result of the exploitation of dense herring schools moving toward the spawning-grounds during a ten-day time extension beyond the usual date of fishing closure. However, it no doubt also reflected the relatively high abundance of Area 25 herring stocks which in the two previous years had been largely unfished because of their late inshore movement (Stevenson, Hourston, and Lanigan, 1951).

TAGGING AND TAG-RECOVERY

The aims of tagging are twofold. Analysis of tag-recovery data permits (1) a description of the extent of movement between and within populations, and (2) a rough calculation of the rate of exploitation of the fishery.

In 1952, tagging operations were continued in the middle east coast, lower east coast, and west coast of Vancouver Island sub-districts, as they have been since 1946–47, and, as in 1951, fish in the central and northern sub-districts were tagged extensively. Methods used in tagging herring and in recovering tags were the same as those employed in previous years.

Tags were recovered during the 1951–52 fishing season* by (1) tag-detectors operated by herring-investigation personnel and (2) magnets tended by plant crews at reduction plants. Recovered tags were derived from the 1951 tagging (15-series) and from taggings of previous years.

Those fishing-grounds which yielded or might have yielded tags during the 1951–52 fishing season were: Area 2B (E)—Burnaby Narrows and Bigsby Inlet; Area 5—Gasboat Pass and Kitkatlah Inlet; Area 6—Laredo Inlet and Myers Pass; Area 7—Kildidt Sound; Area 8—Cousins Inlet and Reid Pass; Area 9—Moses Inlet and Douglas Channel; Area 12—Sargeaunt Pass, Simoom Sound, Greenway Sound, Thompson Sound,

* A list of the places and dates of individual taggings which produced recoveries during 1951–52 will be supplied on request (Supplementary Table I).

and Bones Bay; Area 13—Deepwater Bay; Area 17A—Nanoose Bay; Area 17B—Dodd Narrows; Area 18—Swanson Channel and Satellite Channel; Area 23—Effingham Inlet; Area 24—Sydney Inlet; Area 25—Tahsis Canal, Espinosa Inlet, and Port Eliza Inlet.

During the 1951–52 herring season, tag-detectors recovered tags at three plants. Two were located in Steveston, B.C., at the Imperial and Gulf of Georgia reduction plants. The other detector was located at Seal Cove in Prince Rupert. A tabulation follows, showing the type of detector used at each plant, the percentage efficiency of each detector during the pre-Christmas and post-Christmas periods, and in parentheses are shown the comparable efficiencies at which they operated during the 1950–51 season:—

Detector Installation	Type of Detector	Efficiency while Operating	
		Pre-Christmas	Post-Christmas
Imperial	Wheatstone bridge	59 (90)	87 (71)
Gulf of Georgia	Induction	80 (25)	80 (94)
Seal Cove	Both types	0 (—)	5 (—)

The Imperial detector operated during the pre-Christmas period at an efficiency which was considerably lower than that of the previous year over the same period. While its efficiency was greater in the post-Christmas than in the pre-Christmas period, it developed serious troubles after two days of post-Christmas operation and could not be operated for the rest of the season. The induction-type set, operating at the Gulf of Georgia plant, performed well during the whole pre-Christmas period and the principal part of the post-Christmas period. Its average mechanical efficiency increased from 60 per cent in 1950–51 to 80 per cent in 1951–52. Tag-detection of the new installation at Seal Cove was very unsatisfactory. Generally, many problems arise in the first year's operation of a new detector installation. The speed of the conveyor-belt was insufficient to permit satisfactory operation of the induction-type set. A Wheatstone bridge set which was operated at Seal Cove late in the season performed unsatisfactorily because of a faulty coil mechanism.

The efficiency of recovery of tags taken from the magnets by plant crews depends upon both the mechanical efficiency of the magnet and the diligence of those individuals in returning the tags with pertinent information on recovery to the Pacific Biological Station. To test efficiency, sets of fifty tags differentiable from those taken by the fishery are inserted from time to time during the season in landed fish. The percentage recovered by the magnets and returned to the Biological Station is the index of plant or "magnet" efficiency of recovery. A table of the average 1951–52 efficiency of each plant, with its average 1950–51 efficiency in parentheses, follows in the table below:—

West Coast

Plant	Number of Tests	Average Efficiency of Tests
Kildonan	0 (2)	— (88)
Ecoole	0 (1)	— (90)
Port Albion	0 (2)	— (91)
Nootka	1 (3)	82 (88)
Ceepeecee	2 (1)	69 (68)
Hecate	1 (0)	54 (—)
Average	—	68 (85)

Steveston and Vicinity

Plant	Number of Tests	Average Efficiency of Tests
Imperial	7 (3)	86 (82)
Colonial	3 (3)	83 (74)
Gulf of Georgia	8 (3)	83 (50)
Phoenix	5 (1)	94 (86)
North Shore	3 (1)	97 (54)
Average		89 (69)

Other Localities

Alert Bay	1 (0)	78 (....)
Namu	2 (1)	91 (78)
Butedale	1 (0)	86 (....)
Port Edward	3 (1)	94 (78)
Seal Cove	1 (0)	63 (....)
Average		82 (78)
Grand average		80 (77)

The efficiency of recovery for those west coast plants which were tested was about the same in 1951–52 as in 1950–51. Unfortunately, because of the sporadic nature of the fishery in this sub-district, it was impossible to test Kildonan, Ecoole, or Port Albion plants. Plants at Steveston, and those listed under "other localities," were tested more frequently this year (thirty-four tests in 1951–52 as compared with thirteen in 1950–51). All of them showed increases in efficiency. The principal reason for the increase was apparently related to the fact that plant personnel this year were paid directly for tag-recoveries by a herring-investigation contact-man. They were thus saved the inconvenience of sending tags to the Pacific Biological Station for payment. Also, the increased number of magnet tests in 1951–52 increased the likelihood of reward to the men. Increased incentive might have prompted greater diligence on the part of plant crews and tended toward an increase in efficiency of recovery.

Recoveries by Tag-detectors

The number of detector recoveries in 1951–52 showed a decrease compared with the 1950–51 recovery. A total of 226 tags was recovered from regular spring taggings, and 20 tags were taken from taggings carried out at Sooke in the fall of 1951 just prior to the opening of the fishery. The number of tags taken at each detector installation was as follows: Imperial, 59; Gulf of Georgia, 178; and Seal Cove, 9. Detector recovery in 1950–51 amounted to 259 tags, all from spring taggings. A comparison of the number of tags (from spring taggings) obtained from the various sub-district fisheries in the past two seasons is given in the following tabulation:—

Sub-district Fishery	Number of Detector Returns 1950–51	1951–52
Northern	2	50
Central	111	42
Upper east coast	2	1
Middle east coast	26	34
Lower east coast	30	83
West coast	88	16
Totals	259	226

Increased intensity of tagging in the northern sub-district in 1951 and a heavy 1951–52 fishery accounted for the higher number of returns from northern catches, while the decrease in the number of tags from the central sub-district was largely due to decreased catch. The increase in the number of tags from lower east coast catches was at least partly a result of increased intensity of tagging. Recovery of tags from the west coast of Vancouver Island sub-district showed a sharp decrease in 1951–52. The decrease was largely due to the fact that while heavy west coast fishing was taking place at the end of the fishing season, only one tag-detector, operating erratically, searched the catches for tags. Furthermore, concentration of tags in the west coast catch was somewhat less in 1951–52 (0.0358 tags per ton) than in the previous year (0.0531 tags per ton).

Because of the small number of tags recovered from west coast catches by tag-detectors in 1951–52, no attempt will be made to calculate various population statistics on the west coast stocks, as has been done in previous years. Detector recoveries from some of the other herring populations, however, appear sufficiently numerous to warrant calculation of certain population statistics, and discussion of these statistics will be published later.

Movement between Populations

To study movement between populations, the "probable" number of tags in the various catches is calculated. Since (1) detectors are never 100 per cent efficient in operation and (2) only part of each sub-district catch is searched by the detector, corrections must be applied to the actual number of recoveries to provide the probable number of tags in the catches. The actual numbers of tags recovered by detectors in 1951–52 and the calculated probable numbers of tags in the catches are given in Table II, according to area of tagging, tagging code, and area of recovery. This table is summarized below, according to sub-districts, to provide data pertinent to the analysis of herring movements; the probable number of tags in the various catches are given, and actual numbers of tags on which the calculations were based appear in parentheses:—

Sub-district of Tagging	Sub-district of Recovery						Total
	Northern	Central	Upper East Coast	Middle East Coast	Lower East Coast	West Coast	
Northern	619 (43)	.....	.....	.....	7 (2)	32 (1)	658 (46)
Central	98 (7)	2,631 (32)	.....	13 (3)	.....	.....	2,742 (42)
Upper east coast	.....	.....	3 (1)	.....	.....	.....	3 (1)
Middle east coast	.....	.....	.....	108 (24)	46 (5)	.....	154 (29)
Lower east coast	.....	.....	.....	27 (6)	322 (73)	.....	349 (79)
West coast	.....	70 (1)	.....	4 (1)	14 (3)	1,042 (15)	1,130 (20)
Totals	717 (50)	2,701 (33)	3 (1)	152 (34)	389 (83)	1,074 (16)	5,036 (217)[1]
Catch (in tons)	57,300	39,900	8,250	10,350	41,000	30,000	.....
Probable number tags per ton	0.0125	0.0677	0.0004	0.0147	0.0095	0.0358	.....

[1] The difference between these totals and the corresponding totals in Table II is due to the fact that returns from Sooke taggings are not included.

As in previous years, most of the recoveries were taken from the sub-districts in which they were originally used. This "homing" tendency was most pronounced in the central sub-district—96.0 per cent ($^{2631}/_{2742}$)—but it was also great in the northern, lower east coast, and west coast sub-districts—94.1 per cent ($^{619}/_{658}$), 92.3 per cent ($^{322}/_{349}$), and 92.2 per cent ($^{1042}/_{1130}$) respectively. On the other hand, only 70.1 per cent ($^{108}/_{154}$) of the middle east coast tags were derived from middle east coast catches. Only one upper east coast tag was recovered in 1951–52, a result of complete lack of tagging on the upper east coast since 1946. It will be noted in the above tabulation that the present concentration of tags in the upper east coast population is very low in relation

to tag concentrations in other sub-districts. The heavy concentration of tags in the central and west coast sub-districts reflects recent intensive tagging programmes in those areas.

Movement of herring from the west coast of Vancouver Island to other sub-districts was calculated to be about 8 per cent in 1951–52, somewhat lower than the corresponding emigration noted in 1949–50 (12 per cent) and in 1950–51 (15 per cent). The data suggest that most of the west coast emigration was to the central sub-district—6.2 per cent ($^{7}/_{1130}$)—but since the calculation was based upon only one tag return, little confidence can be placed on the calculated extent of this migration. A movement of 1.2 per cent ($^{14}/_{1130}$) was noted to the lower east coast, the smallest such movement calculated since this type of data has been collected. This extremely small migration is probably related to the present reduced size of the Area 23 stocks, which generally provide most of the west coast herring to lower east coast runs. The reverse movement, that of emigration of lower east coast herring to the west coast, was entirely lacking in the 1951–52 detector returns.

A single northern tag was taken from west coast catches by tag-detectors, but no central tags were recovered on the west coast. Considering the relatively small proportion of the west coast catch that was searched for tags by tag-detectors, these results are not likely to be representative of the extent of herring movement. Plant returns, which are discussed later, suggest that migration of central fish to the west coast is greater than the migration of northern fish to the west coast.

The main movement of central tags was to the northern sub-district—3.6 per cent ($^{98}/_{2742}$); no reciprocal movement of herring from the northern to the central sub-district was shown by detector returns. In 1950–51 detector recovery data indicated no movement in either direction.

Lower east coast herring moved only to the middle east coast, a movement amounting to 7.7 per cent ($^{27}/_{349}$). Middle east coast herring, however, showed a large migration to the lower east coast—29.9 per cent ($^{46}/_{154}$). A generally great interchange of fish between these two sub-districts has been noted in all years of the present tagging programme, except for 1950–51 when a movement of only 2 to 3 per cent occurred in each direction (Stevenson, Hourston, and Lanigan, 1951).

No lower east coast tags were taken in the northern catches, but a 1.1 per cent movement ($^{7}/_{658}$) was noted in the opposite direction.

Detector returns in 1951–52 show a tendency for a southerly movement of herring along the British Columbia coast. The major exception to this general condition was the northward movement of central fish to the northern sub-district, which was not accompanied by a corresponding southward movement from the northern to the central sub-district. The heavy exploitation of the northern stocks in 1951–52 might have accentuated this northerly movement which appeared to be contrary to the general migration pattern.

Movement within Populations

Because of the small number of detector recoveries from the west coast catches in 1951–52, only a general analysis of herring movement within the sub-district is possible. Three Area 23 tags of the 15-series (tagged in 1951) were recovered in Area 23, and none were recovered in other west coast areas. One Area 25 tag of the same series was recovered in Area 25, and one was taken from Area 23 catches. One Area 24 tag was returned in Area 23 catches. Thus, even with the limited number of the returns, the tendency for herring to move in a south-easterly direction along the west coast of Vancouver Island was shown.

The probable numbers of 14-series (1950 taggings) and 15-series (1951 taggings) tags in the central sub-district catches are summarized from Table II in the following

tabulation (actual numbers of tags, on which probable numbers are based, are given in parentheses):—

Area of Tagging	Area of Recovery—14-series		Area of Recovery—15-series	
	6	7	6	7
6	377 (3)	———	880 (7)	———
7	———	140 (2)	———	1,094 (18)
10	———	———	———	140 (2)

Returns from neither the 14-series tagging nor the 15-series tagging showed intermixture of herring between Areas 6 and 7. No Area 6 tags were taken in Area 7, and no Area 7 tags were taken in Area 6 catches. In the previous year, Area 7 tags were not recovered from Area 6, and only two Area 6 tags were returned from the Area 7 fishery (Stevenson, Hourston, and Lanigan, 1951). These data strongly suggest that the two main central sub-district stocks should be considered as separate populations. However, it seems desirable to collect additional data pertaining to this problem before arriving at a conclusion.

As in the previous year, movement of Area 10 herring to Area 7 was noted. Since Area 10 tags were also taken in the middle east coast of Vancouver Island sub-district, it appears that the relatively small Area 10 herring population is subject to wide dispersal.

Movement of herring within the lower east coast sub-district appears to be a different problem than movement of herring within other sub-districts. In the case of most other sub-districts, the inshore migration routes of the various runs to the different fishing areas are relatively discrete, whereas herring of the lower east coast population move from offshore summer feeding-grounds through the Strait of Juan de Fuca to the southern entrance of the Strait of Georgia, from where they follow along the general contour of the Vancouver Island coast through each of the three main fishing areas (Areas 18, 17B, and 17A). Thus movement within populations, as considered with respect to most herring populations, is not applicable to the lower east coast runs, since whether tags are caught in their area of tagging or in another area depends almost wholly on the particular area in which the fishing fleet contacts the main bodies of fish along the migration route within the sub-district. In 1951–52 Area 18 contributed about two-thirds of the sub-district catch, and although the 1951 taggings were fairly evenly distributed between all areas of the sub-district, a preponderance of the tag returns (about 80 per cent, in terms of probable numbers of tags in the catches) was taken from the Area 18 fishery.

In the fall of 1951, 991 herring were tagged at Sooke in the Strait of Juan de Fuca with a view to obtaining further evidence of the inshore migration of lower east coast stocks through the Strait of Juan de Fuca. A total of twenty of these tags was recovered by tag-detectors (Table II), and all of them were from the lower east coast fishery, which took place about two months after tagging. Plant returns accounted for thirty-six recoveries (Table III); thirty of these were considered to have come from lower east coast catches, two from west coast catches, and too much doubt surrounded the exact sub-district of recovery of the other four tags to permit assignment. A similar tagging was conducted in the fall of 1944, when 1,409 fish were tagged at Sooke. In the 1944–45 fishery, seventy-four tags were recovered by tag-detectors, all of which were from lower east coast catches (Tester, 1945); in 1945–46 only one tag was returned, and it came from the lower east coast (Tester, 1946), while in 1946–47 three tags were recovered—two from lower east coast catches and one from Area 23 on the west coast of Vancouver Island (Tester and Stevenson, 1947).

Both Sooke taggings strongly indicated that the main inshore migration route of the lower east coast population is through the Strait of Juan de Fuca. The single west coast

recovery obtained more than two years after the 1944 tagging could have resulted from the limited intermingling known to exist between west coast and lower east coast fish. The two plant returns from the 1951 tagging which were considered to have come from the west coast fishery suggest that a small proportion (about 6 per cent) of the fish at Sooke went back offshore and then moved inshore to west coast fishing-grounds.

Recovery of Tags by Plant Crews

In 1951–52, 4,512 decipherable tags were recovered by plant crews from magnets and plant machinery of sixteen reduction plants. This record recovery constitutes an increase of 119 per cent over that of the previous year. The increase was due primarily to (1) the record large 1950 and 1951 taggings, (2) heavy exploitation of all herring populations, and (3) a system of direct payment of tag rewards to plant crews:—

Plant Name	Number of Tags Recovered	Plant Name	Number of Tags Recovered
Imperial	497	Port Edward	525
Colonial	449	Seal Cove	94
Gulf of Georgia	235	Kildonan	43
Phoenix	370	Port Albion	42
North Shore	317	Nootka	131
Alert Bay	56	Ceepeecee	239
Namu	683	Hecate	33
Butedale	756	Shingle Bay	42

The distribution of tags according to area of tagging and probable sub-district of recovery is given in Table III. While the area of recovery of detector returns is always specific, it is often difficult to determine specifically the area or even the sub-district from which a plant recovery originated. Certain methods (Tester and Stevenson, 1948) are employed to assign as accurately as possible the most probable area of recovery to each tag. It is seen from Table III that 592 tags, or 13.1 per cent, were unclassifiable as to location of recovery. In general, less trouble was occasioned in assigning plant recoveries in 1951–52 than in previous years, since, for the most part, landings from only one fishery entered each plant during any particular part of the season. In the following tabulation, data from Table III have been summarized to show numbers of recoveries according to the sub-district of tagging and the most likely sub-district of recovery:—

Sub-district of Tagging	Probable Sub-district of Recovery							Total
	Northern	Central	Upper East Coast	Middle East Coast	Lower East Coast	West Coast	Indeterminate	
Northern	382	24	—	—	—	1	44	451
Central	112	2,143	3	5	—	8	425	2,696
Upper East Coast	—	—	4	—	—	1	1	6
Middle East Coast	1	2	2	77	6	—	25	113
Lower East Coast	—	1	—	7	132	11	31	182
West Coast	5	9	—	—	—	948	66	1,028
Totals	500	2,179	9	89	138	969	592	4,476[1]

[1] The difference between this total and the total number of plant recoveries obtained previously is due to the fact that returns from Sooke taggings are not included in this tabulation.

The great tendency for tags to be recovered in the sub-district of tagging, noted previously in the analysis of detector returns, was also shown by the plant returns. In both sources of recovery, central herring showed greatest "homing," while middle east coast herring showed the smallest "homing" tendency.

On the basis of plant returns, emigration of west coast fish was unusually small—1.5 per cent ($^{14}/_{962}$). All west coast emigration was to the central and northern sub-districts.

In 1950–51 considerably larger movement of west coast fish to the central and northern populations was calculated (7.5 per cent). Most of this movement in 1950–51 was found to be tags used in the most northerly west coast areas (Areas 26 and 27), and the complete lack of tagging in those areas in 1951 is part of the reason for the apparently reduced west coast emigration in the past season.

Plant returns showed that eight central tags were taken on the west coast, while only one northern tag was recovered from west coast catches, suggesting movements of 0.4 per cent ($\frac{8}{2271}$) and 0.2 per cent ($\frac{1}{407}$) respectively. Thus both plant returns and detector recoveries indicated an almost negligible quantity of northern and central tags in west coast runs. In view of the intensive tagging in the northern and central sub-districts in 1950 and 1951, the results appear to indicate strongly that west coast stocks are not appreciably supplemented by northern and central herring.

There was no indication of movement of west coast fish to the lower east coast from plant returns for the first time since the beginning of the present tagging programme; the movement in the reverse direction was 7.3 per cent ($\frac{11}{151}$), which is large in view of the lack of evidence of such a movement from detector returns, but about average when compared with data from past years.

The main movement of central fish was to the northern sub-district (4.9 per cent ($\frac{112}{2271}$)), closely resembling the 3.6-per-cent movement determined from detector returns. An appreciable emigration of northern fish to the central sub-district (5.9 per cent ($\frac{24}{407}$)) was shown. The lack of such a movement, on the basis of detector returns, was probably largely a result of the relatively small tonnage of central fish examined for tags by tag-detectors.

The movement of lower east coast fish to the middle east coast amounted to 4.6 per cent ($\frac{7}{151}$) on the basis of plant returns. The corresponding movement, calculated from detector recoveries, was 7.7 per cent. The reverse movement, from the middle east coast to the lower east coast—6.8 per cent ($\frac{6}{88}$)—was much smaller than that computed from detector returns (29.9 per cent). Considering the small numbers of tags indicating emigration of middle east coast fish to the central and northern sub-districts and the complete absence of supporting data from detector returns, there is much doubt concerning the extent of the northward movement of middle east coast fish.

Tag returns from both main sources of recovery give no support to the contention frequently expressed by fishermen and others that the changes in the west coast stocks are appreciably affected by emigration of fish away from the west coast or by immigration to the west coast. It was calculated that in 1951–52 about 1,000 tons of west coast fish were caught in other sub-districts, and about 2,000 tons of fish from other sub-districts were taken in west coast catches.

Tagging during the 1952 Spawning Season

The 1952 tagging programme was carried out with the assistance of three seine-boats loaned by fishing companies. Two vessels began tagging operations on February 25th, one operating in the lower and middle east coast sub-districts until March 24th, the other being used on the west coast until March 21st and in the central sub-district from then until April 7th. The third vessel commenced tagging about March 6th on the west coast, moved to the central sub-district by March 24th, and carried out tagging operations in central, northern, and Queen Charlotte Islands waters until April 10th.

The numbers of herring tagged in the various areas in 1951 and 1952 are given in the following tabulation:—

Year	Sub-district and Area of Tagging															
	Queen Charlotte Islands	Northern	Central			Middle East Coast		Lower East Coast				West Coast			
	2B (E)	4	6	7	10	14	15	17A	17B	18	20	23	24	25	26
1951	———	5,091	5,092	7,507	3,027	———	4,087	5,129	2,058	4,074	991[1]	8,583	4,077	8,109	———
1952	4,114	8,089	———	8,837	———	3,013	———	5,034	5,540	———	———	10,058	5,071	8,058	3,073

[1] Tagged in the fall of 1951 after the previous report in this series had been presented for publication.

A total of 60,887 fish* was tagged in 1952, as compared to 57,825 in 1951. More herring were tagged in the west coast sub-district than in the previous year (26,260 as compared to 20,769). Taggings were carried out in all west coast areas except Area 27.

Herring were tagged on the east coast of the Queen Charlotte Islands in 1952—the first tagging made in that sub-district since 400 fish were tagged in the spring of 1940 (Hart and Tester, 1940). Tagging in the northern sub-district was also more intensive than in 1951, but fewer fish were tagged in the central, middle east coast, and lower east coast sub-districts. The 1952 herring-tagging programme was the largest ever carried out in British Columbia.

SAMPLING OF THE CATCHES AND THE SPAWNING RUNS

Knowledge of the relative strength of the various year-classes is basic to a comprehensive understanding of a fish population. Information on relative year-class strength is provided by the determination of the ages of fish taken in random samples from the fishery and spawning runs. In addition, these samples provide data on growth rates, which may reflect changes in feeding conditions. Furthermore, data obtained on sex ratio and development tie together certain aspects of the adult and spawn studies.

A total of sixty-three samples† was taken from the west coast of Vancouver Island sub-district during the 1951–52 season. The distribution of this sampling according to area is given below (comparable numbers for 1950–51 are given in parentheses):—

Area	Number of Samples	
	Fishery	Spawning Runs
23	16 (38)	5 (4)
24	1 (2)	2 (2)
25	37 (2)	1 (4)
26	0 (0)	1 (0)

No samples have been obtained from Area 27 since the 1949–50 season.

* A list of all taggings made in 1952, including information on the date and place of each tagging, will be supplied on request (Supplementary Table II).

† A list of all fishing and spawning samples taken in 1951–52, including places and dates of sampling, numbers of fish of each age, numbers of fish of each sex, and data on maturity, will be supplied on request (Supplementary Table III).

Age Composition

The average percentage age composition (weighted to numbers of fish caught in each area) of the west coast fishing samples is given below for each season since the removal of the quota restrictions in that sub-district:—

Fishing Season	In Year of Age								
	I	II	III	IV	V	VI	VII	VIII	IX–XI
1946–47	+[1]	5.0	53.0	32.1	6.0	2.5	0.9	0.5	0.1
1947–48	+	2.4	58.2	27.8	8.5	2.1	0.5	0.3	0.1
1948–49	+	7.4	45.2	32.9	9.6	3.4	1.0	0.3	0.1
1949–50	+	4.4	68.8	20.5	5.3	0.8	0.2	0.1	0.0
1950–51	+	9.8	35.3	44.5	8.0	1.9	0.5	+	+
1951–52	+	2.6	36.2	23.9	31.6	4.3	1.2	0.2	+

[1] The plus signs indicate percentages of less than 0.05.

The striking feature of the age composition in 1951–52 is the large proportion of the V-year fish (1947 year-class), forming nearly a third of the catch. This is the largest contribution of V-year fish to the fishing stock since detailed age-composition data were first recorded (1929–30), and is four times the average percentage contribution of V-year fish during the last five years. Since it entered the fishery in 1949–50, this year-class has made a higher contribution to the percentage age composition of the herring stocks than any other year-class in the last nine years.

The great strength of the 1947 year-class has been evident since its first summer, when large numbers of I-year fish were seen in inshore waters (Tester and Stevenson, 1948). In the spring of 1949 it entered the spawning runs in tremendous numbers as II-year fish (Stevenson, 1950); as III- and IV-year fish, it dominated the catch (Stevenson and Lanigan, 1950; Stevenson, Hourston, and Lanigan, 1951). During the 1951–52 season it formed about the same proportion of the catch as the newly recruited 1949 year-class (III's). Since negligible recruitment occurs after the fifth year, it is unlikely that the 1947 year-class will form an important part of the fishing stocks in future fishing seasons.

The relative weakness of the 1948 year-class was again evident in the 1951–52 stocks. Its contribution to the catch as IV-year fish was one of the smallest in recent years. The newly recruited 1949 year-class also showed indications of relatively low abundance. It failed to form a significantly higher proportion of the population than did the weak 1948 year-class in the previous year.

On the basis of the number of fish contributed by each year-class to the fishery (tabulated below as millions of fish), the relative weakness of both the 1948 and 1949 year-classes is particularly striking (Fig. 3 (A)). As III-year fish, each supplied only a little over one-third of the contribution made by the immediately preceding year-classes.

Fishing Season	Age									
	I	II	III	IV	V	VI	VII	VIII	IX+	Total
1946–47	0.13	27.02	288.72	174.70	32.53	13.65	4.88	2.49	0.47	544.79
1947–48	0.13	10.03	240.18	114.60	35.16	8.76	2.24	1.10	0.56	412.76
1948–49	0.30	36.83	224.02	163.90	47.52	16.84	5.05	1.66	0.45	495.67
1949–50	0.13	14.89	233.67	69.68	17.86	2.69	0.65	0.20	0.00	339.77
1950–51	0.08	22.27	80.17	100.93	18.05	4.36	1.04	0.04	0.04	226.98
1951–52[1]	0.06	6.08	86.39	56.99	75.55	10.20	2.89	0.53	0.06	238.76

[1] The number of fish of each age in the catches of each individual west coast area will be supplied on request (Supplementary Table IV).

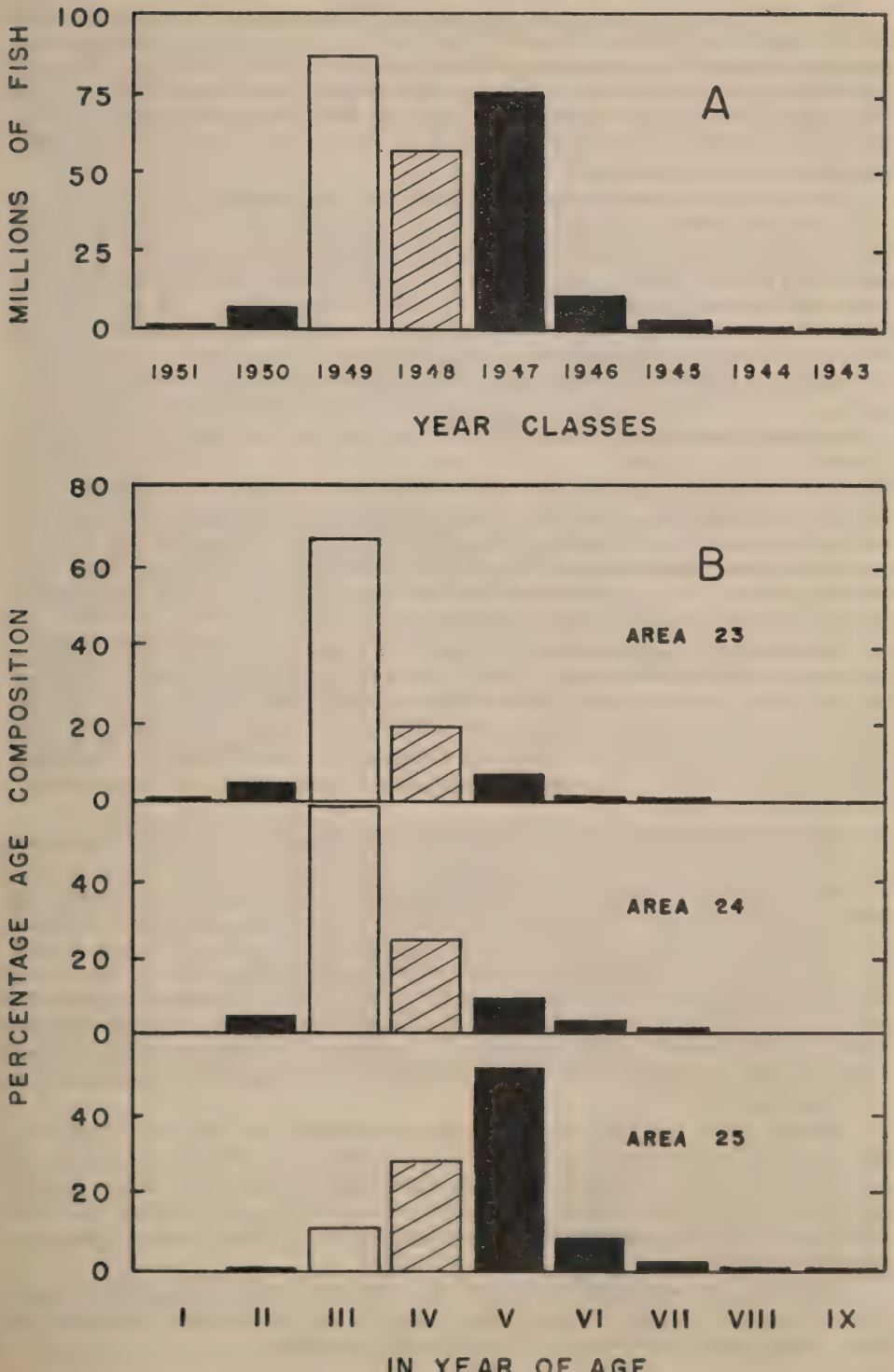


Fig. 3. Diagrams showing (A) the total number of herring in each year-class caught by the commercial fishery in 1951–52, and (B) the average age composition of samples from the commercial catches in Areas 23, 24, and 25.

The 1950 year-class (as II-year fish) and the 1951 year-class (as I-year fish) both made the lowest contribution to the fishery that has been made by fish of their age since the present study of the west coast population was begun in 1946. This may be the forerunner of two particularly weak year-classes in the fishery. The decrease in 1951–52 in the number of the younger herring in the catch has been more or less balanced by an increase in the number of fish of all ages over IV years, with the result that the total catch was approximately the same as in 1950–51.

A pronounced difference in age composition was noted between the two main fishing areas—Area 23 (Barkley Sound) and Area 25 (Esperanza Inlet). In Area 23, III-year fish made up two-thirds of the catch, with relatively large proportions of II- and I-year fish (Table IV and Fig. 3 (B)). In Area 25, however, V-year fish dominated the catch, with relatively strong contributions by VI- to IX-year fish. The proportion of III-year fish in Area 25 was only one-sixth of that in Area 23, while the amount of V-year fish in Area 23 was less than one-sixth of that in Area 25. Thus in 1951–52 the tendency noted previously (Stevenson, Hourston, and Lanigan, 1951) for older fish to be better represented in runs of the more northerly west coast areas was distinctly shown.

Because of the relative weakness of the 1948 year-class, the catch in Area 25 was expected to be lower in 1951–52 than in 1950–51, provided the exploitation was similar (Stevenson, Hourston, and Lanigan, 1951). The 1948 year-class did contribute relatively few fish to the fishery, but the contribution of the 1947 year-class was maintained at a high level even as V-year fish. Consequently, population abundance in Area 25 was relatively well maintained in 1951–52. The 1951–52 catch was about three times that of the previous year, but part of the increase is undoubtedly due to higher exploitation resulting from an extended fishing season in 1952.

On the basis of the good showing of the 1949 year-class in the 1950–51 catch in Area 23, it was predicted that the 1951–52 catch in that area would be larger. Although a slightly greater number of III-year fish (1949 year-class) was caught in 1951–52 than in the previous year, the large reduction in numbers of II- and IV-year fish (1950 and 1948 year-classes respectively) resulted in a decreased total catch for the area (compare Supplementary Table IV, Stevenson, Hourston, and Lanigan, 1951, and Supplementary Table IV of this report).

The age composition in Area 24 was similar to that in Area 23—a possible indication of relatively free mixing between the two areas.

The strength of the incoming 1950 year-class will be the major factor governing the abundance of herring on the west coast in 1952–53. As in the past, newly recruited III-year fish are generally of relatively greater importance in the Area 23 fishery than in the Area 25 fishery. Considering its contribution (as II's) in the 1951–52 fishing and spawning samples, the 1950 year-class appears to be of about the same strength as the 1949 and 1948 year-classes in Area 23, but much weaker than either of these year-classes in Area 25. On the basis of this information, it appears unlikely that the 1952–53 catch in Area 23 will exceed that in 1951–52, providing that the fishing effort is similar to that of the previous year.

Since the 1947 year-class, which heavily supported the Area 25 population in the past three years, is not expected to contribute appreciably to the 1952–53 catch, reduced abundance in Area 25 in the coming season is anticipated. It is most unlikely that the loss of the 1947 year-class will be made up by the contributions of the 1948 and 1949 year-classes. Providing exploitation is no greater than in the 1951–52 season, a decrease in catch is expected.

Considering the west coast as a whole, the 1952–53 catch is expected to be lower than in the previous season if fishing effort is similar, and with greater dependence on younger year-classes, the average size of the fish will be smaller.

Sex Ratio and Stage of Development

The sex ratio (number of females divided by number of males) and sexual development of the herring in samples taken from the 1951–52 commercial fishery and the 1952 spawning runs are given in Table V. The sex ratio for the sub-district was typical of the general trend noted in most recent years; namely, that males and females were about equally abundant in the commercial catch (with a slight tendency for the females to predominate), whereas the males were more numerous than females in the spawning runs. The difference in sex ratio between samples from the fishery and those from the spawning runs was attributed to the fact that the average age of fish in the spawning runs was less than that of the fishing schools (Table IV). It has been previously noted that the proportion of males to females is generally greater in samples of younger fish (Stevenson and Lanigan, 1950). In Area 25, where the spawning population was made up of relatively old fish, the females dominated, as they did in the commercial catch. The average age of the spawning fish decreased from Area 25 to Area 24 to Area 23 to Area 26, and with this decrease, the sex ratio diminished from 1.17 to 0.80 to 0.64 to 0.47. This phenomenon could be produced by generally slower maturity of females or higher mortality in males.

Immature fish were found in spawning runs for the second successive year. In 1951–52 they were found only in Area 23, where they made up 1.4 per cent of the catch. On the other hand, the percentage of immature fish in the commercial runs was the lowest (2.5 per cent) during the six years of the study. This situation could result from a later-than-usual inshore movement of the immature fish.

Spent fish were taken in the commercial catch in 1951–52 for the first time since 1946–47, but in very small numbers (less than 1 per cent). They were taken in Esperanza Inlet, where the date of closure for the fishery was extended for ten days after February 5th. Early spawnings were beginning when the fishery was closed, and consequently some of the fish could have either spawned before they were caught, or on the seine while being caught.

Average Length and Weight

Differences in average length and weight between two comparable populations are probably mainly due to differences in the environmental conditions (food-supply, temperature, etc.) which influence growth. Consequently, annual variations in the average size of fish from a given region may be used as indicators of changes in these environmental conditions. Average weights of the various age-groups are also used, in conjunction with percentage age composition, to calculate the number of fish of each age in the annual catch. The average lengths and weights of herring from the commercial catch in 1951–52 are given in Table VI for each age-group; comparable lengths for fish from the spawning runs are given in Table VII. Weights are not taken for the spawning fish mainly because of the variation in weight involved in spent and unspent fish.

The average lengths and weights of herring from the major age-groups in the fishery are given below:—

Year	In Year of Age				
	II	III	IV	V	VI
Length in millimetres—					
1946–47	166	187	203	213	222
1947–48	161	188	201	210	220
1948–49	159	188	201	213	222
1949–50	164	190	202	212	220
1950–51	158	188	204	215	220
1951–52	159	187	205	217	226
Weight in grams—					
1946–47	57	86	113	133	151
1947–48	53	90	110	129	150
1948–49	50	87	111	138	158
1949–50	56	94	117	137	152
1950–51	50	88	114	135	149
1951–52	53	90	114	139	157

Fish of IV years and over were longer in 1951–52 than in any other season during the current study and tended to be heavier. The younger fish were about average size. Since, as a whole, the west coast fish were larger than average in 1951–52, better than average feeding conditions during the 1951 growth season might be indicated. Variations in preceding seasons have been discussed previously (Stevenson, Hourston, and Lanigan, 1951).

There was no difference in the average weights of the two major west coast populations (Area 23 and Area 25), so their 1951 feeding conditions were presumed to be similar. However, the Area 25 fish might have had better environmental conditions during their earlier years, for they were consistently longer than those from Area 23. Area 24 fish resembled the herring from Area 23 both in size and weight.

The length differential between fish sampled from the fishery and those from the spawning runs, which was noted in 1950–51 (Stevenson, Hourston, and Lanigan, 1951), was not evident in the 1951–52 samples. Only relatively small differences were noted in the data for Area 23 and Area 25. Differences shown in Area 24 were greater than those in either Area 23 or Area 25, but since only one sample was taken from the Area 24 fishery and two from spawning runs, they may not represent any real dissimilarity between the growth of the spawning and fishing stocks.

EXTENT AND INTENSITY OF SPAWNING

For the sixth consecutive year, members of the herring-investigation staff surveyed the west coast of Vancouver Island spawning-grounds. The main purpose of this phase of the research is to estimate the amount of spawn (in statutory miles) deposited in this sub-district during successive years. This information is used to assess from year to year the relative abundance of the spawning stock, that portion of the population which escapes the preceding winter fishery. This information also provides basic data for early life-history studies. Methods used in this survey were similar to those of previous years (Tester and Stevenson, 1948). As in the past, the spawning-grounds in each area were independently surveyed by fisheries officers.

West coast spawnings in 1952* resembled the general spawning pattern of previous years (Stevenson and Lanigan, 1950; Stevenson, 1950; and Tester and Stevenson, 1947, 1948). The main spawning-grounds were:—

Area 23: Toquart Bay and Macoah Passage.

* A list of the individual spawning localities, with dates, intensity, and extent of spawn depositions, will be supplied on request (Supplementary Table V).

Area 24: Cypress Bay, Mosquito Harbour, Big Whitepine Cove, and Riley's Cove.

Area 25: Port Langford and Nuchatlitz Village vicinity.

Area 26: Gay Passage and Union Island.

Area 27: Leeson Harbour and Greenwood Point.

Early spawnings, in February, took place at Port Langford (Area 25), Macoah Passage and Useless Inlet (Area 23), Mosquito Harbour (Area 24), and Winter Harbour (Area 27). These were followed by general spawnings on customary grounds during March. Late spawnings, in April, occurred at Toquart Bay (Area 23), Kendrick Inlet (Area 25), and Leeson Harbour (Area 27).

The most striking features of the 1952 spawnings were:—

(1) The lack of spawning at Mayne Bay, Stopper Islands, and the Sunshine Bay region (Area 23).

(2) The small, deep, and very heavy spawn deposition recorded at Riley's Cove and in Millar Channel (Area 24) for the first time in the six-year period of the investigation.

(3) A large spawning at Nuchatlitz Village for the second consecutive year (Area 25).

(4) The complete lack of spawning in the Port Eliza-Queen Cove (Area 25) vicinity for the third successive year.

(5) A general decrease in the number of spawnings in Area 25.

(6) The absence of spawnings in Nasparti and Malksope Inlets (Area 26) for the first time, and the lack of spawnings in Ououkinsh Inlet (Area 26) for the second successive year.

The extent of spawn deposition on the west coast of Vancouver Island was less in 1952 than in any year since 1947, and about 35 per cent less than in 1951. The data for the 1951 and 1952 spawnings are tabulated below (in statutory miles) according to area:—

Area	Extent in Miles 1951	1952
23	8.8	6.2
24	11.4	5.6
25	28.3	21.4
26	1.5	1.4
27	4.9	1.1[1]
All areas	54.9	35.7

The decrease in spawning extent was reflected in all areas of the sub-district, except in Area 26, where the total extent was similar in each of the past two years. The reduction in the extent of spawn deposition in Area 24 was the greatest of any west coast area, the 1952 total amounting to only about half that of 1951. Small spawnings at Mosquito Harbour and Cypress Bay were responsible for the reduced spawn deposition in Area 24. The extent of spawning in Area 23 was the lowest in the past six years. This decrease resulted mainly from the absence of a spawning in Mayne Bay and from reduced spawnings in Useless Inlet and Toquart Bay. Spawnings in Area 25 were reduced in extent by about 25 per cent, but the recurrence of a large spawning (17.5 miles of spawn) in the vicinity of Nuchatlitz kept the spawning at a generally high level; for the second consecutive year this area comprised more than half of the total west coast spawning.

[1] Adverse weather conditions prevented surveys of spawnings in Klaskish and Klaskino Inlets. It is doubtful, therefore, that the actual decrease in Area 27 spawning was as great as that recorded.

The average spawning intensity on the west coast this year was slightly greater than that of the 1951 spawnings. A comparison of the average spawning intensity in 1951 and 1952 is summarized below:—

Area	Average Spawning Intensity 1951	1952
23	2.9	2.6
24	1.3	2.3
25	3.4	3.7
26	3.4	2.8
27	3.1	3.2
All areas	2.9	3.3

Average intensities of spawn deposition are calculated by weighting the various intensities of the individual spawnings—very light, light, medium, heavy, and very heavy —in the ratio of 1, 2, 3, 4, and 5 respectively, and by correcting for extent of the individual depositions.

The increase in average spawning intensity compensated in some measure for the great decrease in spawning extent, but, in spite of this, an actual decrease in the amount of spawn deposited on the west coast was considered to have occurred. The pronounced reduction in extent of spawning in Area 24 was largely balanced by a tremendous increase in spawning intensity. Also, the reduction in spawning extent in Area 25 was apparently offset, in part, by increased intensity of deposition. In Areas 23 and 26, however, the decrease in extent of spawn was accompanied by a decrease in intensity.

The decreased west coast spawning in 1952 appears to be a direct result of reduced population abundance, caused by entrance of the relatively weak 1948 and 1949 year-classes into the fishing stocks. There is no evidence that the 1952 spawn deposition is below that necessary to maintain the population. A spawning even smaller than that of 1952 produced the extremely abundant 1947 year-class (Tester and Stevenson, 1948).

Data on spawn deposition have shown that Area 23 stocks have decreased in the past three years, while the Area 25 fishing population has maintained a generally high level during this period, despite the decrease noted in 1952. The reduced Area 23 population is a consequence of the poorly recruited 1948 and 1949 year-classes, while the Area 25 stocks from the 1949–50 to the 1951–52 season were sustained by the abundant 1947 year-class. Light exploitation in Area 25 in 1949–50 and 1950–51 resulting from late inshore migration of the fish apparently assisted in maintaining the stocks of that area at a high level (Stevenson, Hourston, and Lanigan, 1951). Increased exploitation in the past season, resulting from a time extension of the fishery-closure date (from February 5th to February 15th), probably accounted for part of the spawn reduction in 1952, but low recruitment from the 1948 and 1949 year-classes undoubtedly had some effect on abundance of the Area 25 spawning stocks.

DISCUSSION

An analysis of the data accumulated in 1951–52 on catch statistics, age composition, and spawning deposition of the west coast of Vancouver Island population has been given in the foregoing sections of this report, as well as an analysis of the movement of herring between all major herring populations. The purpose of the present section is to assemble these results and discuss them in terms of the comparative management study being carried out on the west coast and lower east coast herring stocks.

For the first time since the present study began, there was a definite indication of a decrease in population abundance on the west coast. The slight increase in the west coast catch in 1951–52 over that of the previous year occurred in spite of a pronounced reduction in the abundance of the southerly west coast stocks (Area 23), and only because of a greater exploitation of the runs in the more northerly section of the sub-

district (Area 25). The increased exploitation in Area 25 was effected through a time extension of the fishery.

The extent of spawn deposition, an index of the size of the escapement from the fishery, reached the lowest level since 1947 for the west coast as a whole. In Area 23 the spawning extent was the smallest of the entire period of the present study. The extent of spawning in Area 25 in 1952 showed the first downward trend since before the present study was initiated. Although the decrease in the Area 25 spawning was probably largely a result of the high catch (which was double that of the two preceding seasons combined), it is known that larger catches (as, for instance, that of 1948–49) were followed by greatly increased extent of spawn deposition (Stevenson, 1950). This suggests that the Area 25 stocks, as well as those of Area 23, were not maintained at their former high level by recruitment in the past year.

Analysis of the relative contribution of various year-classes in the fishery provides a logical explanation of the reduced population abundance on the west coast. The 1951–52 catch contained an unusually high proportion of V-year fish (1947 year-class). This is the third consecutive season that the 1947 year-class comprised a considerable portion of the west coast catches (Stevenson, Hourston, and Lanigan, 1951), a fact that indicates not only the great strength of the year-class, but also the relatively poor recruitment of the 1948 and 1949 year-classes. The recruitment of the 1947 year-class in 1951–52, as V-year fish, would be expected to be considerably less than the recruitment of this year-class in either of the two previous seasons (at ages III and IV). Even so, the contribution of this year-class to the 1951–52 stocks was large in comparison to that of either the 1948 or 1949 year-class (IV- and III-year fish respectively), which were in their first and second years of major recruitment—striking evidence of the weakness of the latter two year-classes. Unfortunately, an estimate of the relative size of the west coast population in 1951–52 as compared to that in the previous season is not available because of the small number of tag-detector recoveries obtained from the 1951–52 west coast fishery.

When the age composition of the individual area fisheries on the west coast is considered, it is seen that the Area 23 fishery was mainly dependent upon the relatively poor 1949 year-class (III's), thereby resulting in greatly reduced population abundance. In Area 25, population abundance was maintained near to the level of the previous year, principally due to the large contribution of the 1947 year-class.

In contrast to the decrease in population abundance on the west coast, the lower east coast herring population showed an increase in abundance in 1951–52. Following the taking of the fixed catch quota of 40,000 tons, a record high spawn deposition occurred, exceeding by 56 per cent the spawning extent of the previous year. Heavy recruitment of the 1949 year-class (III-year fish) and an appreciable contribution from the 1948 year-class (IV-year fish) appear to have been largely responsible for the increased abundance. The 1947 year-class, which was prominent in the more northerly west coast fishery, was of only minor importance in the lower east coast stocks. In view of the evidence indicating increased abundance of lower east coast stocks, the significant reduction in catch per unit of effort (110.7 tons per seine per day in 1950–51 against 66.9 tons per seine per day in 1951–52) is difficult to explain. Possibly the availability of the fish to the fishing fleet was influenced by the extremely late commencement of the fishery (November 15th), the interruption of the fishery by transference of seining-vessels to more productive fishing-grounds, or by a later-than-usual inshore movement of the fishing runs.

By the end of the fifth year of the comparative study of these two populations, it was noted that abundance had remained generally high during the five-year period, both in the population with quota restrictions on catch and in the population on which no catch restriction by quota was imposed (Stevenson, Hourston, and Lanigan, 1951). Although it appeared that natural limitations on catch in Area 25 had assisted in main-

taining population abundance on the west coast, the results of the study could be interpreted as indicating that the fixed quota on the lower east coast had not aided in stabilizing population abundance. In the light of results of the sixth year's investigation, what conclusions can be drawn? Is the decrease in west coast abundance directly attributable to fishing without quota limitation or is the decrease a result of reduced recruitment occurring through the operation of factors other than fishing?

In the following tabulation, catch and extent of spawn deposition in the two sub-districts are shown for the first three years of the present study:—

Sub-district	Catch, 1946–47	Spawn Deposition, 1947	Catch, 1947–48	Spawn Deposition, 1948	Catch, 1948–49	Spawn Deposition, 1949
	Tons	Miles	Tons	Miles	Tons	Miles
West coast of Vancouver Island	59,000	32.5	45,200	44.0	55,900	41.1
Lower east coast of Vancouver Island	36,500[1]	9.9	39,900	17.4	40,100	20.9

[1] Because of a change in sub-district boundary, the entire quota allotment was not taken within the present lower east coast boundaries in 1946–47.

The 1947, 1948, and 1949 year-classes on the lower east coast have proven to be above the average strength of year-classes of the past fifteen years. The amounts of spawn deposition from which they were derived was indicative of their order of strength (the 1949 year-class being the strongest and the 1947 year-class the weakest), but not of the absolute amount of their recruitment.

On the other hand, the amount of spawn deposited on the west coast has given no indication of the resultant year-class strength. The 1947 year-class, derived from the smallest spawning, has been one of the most productive year-classes of recent years, whereas the 1948 and 1949 year-classes, originating from somewhat greater spawnings, were amongst the least productive. Restriction of the record west coast catches of the 1946–47 to 1948–49 period by fixed quota would have tended to increase the unusually large spawnings of that period. Because of the lack of direct connection between spawn deposition and year-class strength, it appears unlikely that still greater spawnings than those which occurred from 1947 to 1949 would have given rise to more productive year-classes and to increased west coast population abundance in 1951–52.

From spawning and catch data a rough indication of the survival from spawn to maturity can be obtained in each of the two populations. The average west coast spawn deposition of 39.2 miles for the 1947 to 1949 period was followed by an average catch of 30,800 tons from 1949–50 to 1951–52, the seasons in which the catch was largely comprised of fish originating from the 1947 to 1949 spawnings. Comparable figures for the lower east coast show that an average of 16.1 miles of spawn preceded an average catch of 40,800 tons. The striking difference in spawn survival in the two populations suggests a basic difference in the conditions which influence survival in the two stocks. Recently, data were obtained which indicated that poor year-classes on the west coast were formed when certain current conditions off the west coast of Vancouver Island existed during the presumably critical period of larval life in the herring life-history (Stevenson, 1950). If such conditions are not present, at least to the same extent, in the waters of the Gulf of Georgia, higher survival of lower east coast spawn would be expected, and large fluctuations in year-class strength and population abundance, such as are found on the west coast, would not occur.

If it is assumed that such a fundamental difference exists in the two populations under investigation, a comparative study may not be strictly possible. The rough correlation that was previously suggested between spawn deposition and year-class strength on the lower east coast may signify that the spawning stock is being kept close to the critical minimum, below which a close relationship between spawning and resultant year-class strength would be anticipated (Tester and Stevenson, 1947). If this is so,

removal of catch restrictions on the lower east coast may endanger the spawning population. On the other hand, in view of the great fluctuation in survival of west coast spawn, and the natural limitations on catch imposed by late inshore migration, as noted in 1949–50 and 1950–51 (Stevenson, Hourston, and Lanigan, 1951), restriction of catch by fixed quota may serve no useful purpose in maintaining west coast abundance. Investigations being carried out on early life-history phases should shed light on these possibilities.

Continuance of the study is expected to provide results on the effect of non-quota fishing on the diminished west coast population. In previous reports, the necessity of carrying out the present investigation during a period of generally low recruitment was pointed out. Little is known at present on the role that natural limitations to catch will play on the exploitation of the stocks under such condition of abundance. Present indications of the west coast recruitment which will take place in the coming year suggest that population abundance will remain relatively low on the west coast in 1952–53.

SUMMARY

This is the sixth in a series of annual reports on the comparative study of changes occurring in two major herring populations, one of which (that of the west coast of Vancouver Island) is not subjected to quota restrictions on catch, while the other (that of the lower east coast of Vancouver Island) is held to an annual fixed quota of 40,000 tons.

The west coast fishery in 1951–52 (30,000 tons) produced the second smallest catch of the six-year period. Average catch per unit of effort was almost as high as in the years of greatest catch, a result considered to be due to exceptionally efficient fleet deployment rather than great population abundance. Extent of spawn deposition on the west coast in 1952 suggested that the amount of fish that escaped the fishery was less than in any year since 1947. Thus it appeared that population abundance was considerably reduced from that of 1950–51. Spawning data indicated that the main southern west coast stocks (Area 23) suffered relatively greater reduction than the more northerly west coast runs (Area 25). More intensive exploitation of the Area 25 runs occurred in 1951–52 than in the two previous years, principally because of the ten-day extension of fishing past the regular closure date of February 5th.

The decrease in population abundance on the west coast was considered to be largely a result of the recent entrance of two year-classes of generally low production (1948 and 1949 year-classes). These year-classes (as III- and IV-year fish) were the main contributors to the Area 23 fishery. The 1947 year-class, which supplied the main bulk of the 1949–50 and 1950–51 west coast fisheries, was still abundant in the Area 25 stocks as V-year fish in 1951–52 and, as a result, prevented a decrease in population abundance of the magnitude of that which occurred in Area 23.

In contrast to the decrease in west coast abundance, population abundance on the lower coast of Vancouver Island showed a substantial increase in 1951–52. The spawning population, as evidenced from extent of spawn records, showed a phenomenal increase over that of the previous year (56 per cent). The 1947 year-class was of negligible importance on the lower east coast in 1951–52, but the 1949 year-class (as III's) was recruited in large numbers and the 1948 year-class (IV's) made an appreciable contribution to the stocks.

The present difference in the abundance of the two populations under investigation is not considered to be a result of the effect of quota restrictions on the lower east coast fishery. The difference is obviously a direct consequence of dissimilarity in the recruitment of the individual year-classes to the two populations. In recent years the year-classes entering the lower east coast stocks have been generally more uniformly productive than those recruited to the west coast population. There is a strong suggestion from

early life-history studies that oceanographic conditions on the west coast may tend to cause greater variation in year-class strength than conditions on the lower east coast of Vancouver Island. This indication of a fundamental difference between the two populations is strengthened by data which show a major difference in the rates of survival between spawning and recruitment. In view of this apparently fundamental difference, the present comparative study may be considerably complicated. It appears possible that quota restrictions may serve a useful purpose when applied to the lower east coast population but not when applied to the west coast fishery. Further investigation is required before results can be conclusive.

Analysis of tag returns showed a pronounced " homing " in all major populations, as noted in previous years. Tag-recovery data suggested that smaller than usual quantities of fish emigrated from and immigrated to the west coast in 1951–52. Tag-detector returns showed a general southerly migration pattern over the British Columbia coast.

ACKNOWLEDGMENTS

The herring investigation is sincerely appreciative of the various types of assistance provided during the 1951–52 season by fishing companies, herring fishermen, and government fisheries departments.

Special thanks are extended to the fishing companies for the continuance of their support to herring research, without which the present intensive investigation of the herring-fisheries could not be maintained. British Columbia Packers Limited loaned the *Bessie Mac* for general contact work during the fishing season and for tagging in the spring of 1952, permitted installation of tag-detectors at their Steveston (Imperial) and Prince Rupert (Seal Cove) plants, and provided facilities for sampling the catches. The Canadian Fishing Company, Limited, loaned the *Pacific Queen* for tagging work, and made space available at their Steveston (Gulf of Georgia) plant for tag-detection and sampling. A third tagging-vessel (the *B.C. Pride*) was loaned by Nelson Brothers Fisheries, Limited. Anglo-British Columbia Packing Company provided scout-boats and other equipment which were used in connection with the tagging survey. Acknowledgment must also be given to the staff members of various plants for their valuable work in collecting herring samples from the plant landings. In addition to the foregoing assistance, the interest shown by the companies and their plant managers and staffs in herring research was greatly appreciated.

The captains of most seiners of the fishing fleet again provided various statistics on catch through filling out and submitting pilot-house records. The sincere efforts and goodwill of the captains and crews of the tagging vessels constituted an important factor in the successful completion of the large 1952 tagging programme. For this assistance and for the general concern of all herring fishermen in herring research, the herring investigation is truly thankful.

The herring investigation is also grateful for the considerable assistance rendered by the Federal Department of Fisheries through the Chief Supervisor, A. J. Whitmore, and the regional supervisors in Nanaimo and Prince Rupert. Final catch records of all fishing areas were provided, and tentative catch totals were made available during the progress of each fishery. In addition, surveys of the extent and intensity of herring-spawning in all coastal areas were again undertaken. In consideration of the tremendous amount of effort required to carry out these surveys, special thanks are extended to the fisheries officers who participated.

The interest of the Provincial Department of Fisheries and its Deputy Minister, G. J. Alexander, in continuing the publication of this series of reports is gratefully acknowledged. The present annual report is the sixteenth of the series.

The conscientious endeavours of the staff members of the herring investigation were sincerely appreciated during the past year. A. S. Hourston, assistant scientist, undertook

the analysis of the sampling data included in this report, and, in addition, he was responsible for the studies carried out on juvenile herring and for a special study of the herring of the northern sub-district. The compilation and analysis of the tagging data were the chief responsibility of K. J. Jackson, junior scientist. D. N. Outram, junior scientist, undertook the supervision of the spawning studies, which included those reported here and others concerned with spawn mortality.

The administrative assistant of the investigation, G. T. Taylor, assumed chief responsibility for the compilation and analysis of the catch statistics of all herring-fisheries, and gave considerable assistance in the assembling of the various sections of this report.

R. S. Isaacson and M. Bakich, laboratory technicians, were responsible for making age determinations on all fish sampled in the various fisheries and spawning runs, and for making preliminary analysis of sampling data from all populations except that of the west coast. The former staff member also supervised the compilation of the age and growth data, and the latter undertook studies on structure and types of scales.

Most staff members at one time or another assisted in the field work connected with sampling, tag-recovery, spawn studies, and juvenile studies. A. G. Paul, senior field technician, undertook major responsibilities in the tagging and tag-recovery programmes and in the maintenance of non-electrical equipment. J. H. Larkman, field technician, serviced and overhauled tag-detectors and other electrical equipment, and also carried out various other duties connected with tag-recovery and tagging. Other members of the technical staff, B. Wildman, K. A. Herlinveaux, J. A. Saker, R. D. Thicke, J. A. Bond, J. S. Rees, and E. W. Stolzenberg, assisted in field programmes and in preliminary analysis of field data. Stenographic and clerical duties were efficiently carried out by Miss Alice Nyquist and Miss Mary Cairns.

The senior author assumes responsibility for the general interpretation of the results of the 1951–52 studies which are presented in this report.

The counsel and encouragement offered by Dr. J. L. Hart, Director of the Pacific Biological Station, during the past year is acknowledged with sincere thanks.

REFERENCES

Hart, J. L., and Tester, A. L. (1940): The tagging of herring (*Clupea pallasii*) in British Columbia: insertions and recoveries during 1939–40. Rept. British Columbia Fish. Dept., 1939, pp. 42–66.

Stevenson, J. C. (1950): Results of the west coast of Vancouver Island herring investigation, 1948–49. Rept. British Columbia Fish. Dept., 1948, pp. 37–85.

Stevenson, J. C., and Lanigan, J. A. (1950):* Results of the west coast of Vancouver Island herring investigation, 1949–50. Rept. British Columbia Fish. Dept., 1949, pp. 41–80.

Stevenson, J. C.; Hourston, A. S.; and Lanigan, J. A. (1951):* Results of the west coast of Vancouver Island herring investigation, 1950–51. Rept. British Columbia Fish. Dept., 1950, pp. 51–84.

Tester, A. L. (1945): Tagging of herring (*Clupea pallasii*) in British Columbia: insertions and recoveries during 1944–45. Rept. British Columbia Fish. Dept., 1944, pp. 45–63.

——— (1946): Tagging of herring (*Clupea pallasii*) in British Columbia: insertions and recoveries during 1945–46. Rept. British Columbia Fish. Dept., 1945, pp. 43–66.

Tester, A. L., and Stevenson, J. C. (1947): Results of the west coast of Vancouver Island herring investigation, 1946–47. Rept. British Columbia Fish. Dept., 1946, pp. 42–71.

——— ——— (1948):* Results of the west coast of Vancouver Island herring investigation, 1947–48. Rept. British Columbia Fish. Dept., 1947, pp. 41–86.

* Reprints were published in year following the date of publication of report.

TABLES

Table I.—Catch (Tons), Fishing Effort (Total Number of Active Fishing-days Expended by All Seine-boats), and Catch per Unit of Effort (Average Catch per Seine per Day's Active Fishing) for West Coast Areas during the 1951–52 Fishing Season.

Area	Estimated Catch	Fishing Effort[1]	Catch per Unit of Effort
23	11,200	158.0	70.9
24	660	18.0	35.6
25	18,100	211.0	85.9
26	40	0.5	80.0
27	——	3.0	——
Totals	30,000	395.5	75.8

[1] The total number of active fishing-days is calculated to the nearest whole number from catch per unit of effort based on incomplete data and from estimated catch.

Table II.—Probable Number of Tags in the Catches during the 1951–52 Season, Based on Detector Returns, with Actual Number of Recoveries Shown in Parentheses[1]

Tagging Area	Tagging Code and Year	Area of Recovery										Total
		5	6	7	12	13	17A	17B	18	23	25	
4	15T (1951)	323 (23)										323 (23)
	15U (1951)	208 (14)							7 (2)	32 (1)		247 (17)
5	14CC (1950)	88 (6)										88 (6)
6	14AA (1950)		126 (1)									126 (1)
	14BB (1950)	14 (1)	251 (2)									265 (3)
	15V (1951)	28 (2)	754 (6)									782 (8)
	15W (1951)	56 (4)	126 (1)									182 (5)
7	14HH (1950)			140 (2)								140 (2)
	15X (1951)			155 (3)								155 (3)
	15AA (1951)			538 (9)								538 (9)
	15BB (1951)			401 (6)								401 (6)
10	15CC (1951)			140 (2)		13 (3)						153 (5)
12	10H (1946)				3 (1)							3 (1)
14	14A (1950)					13 (3)						13 (3)
15	13A (1949)					4 (1)						4 (1)
	14B (1950)						5 (1)					5 (1)
	14C (1950)					20 (4)		26 (1)				46 (5)
	15A (1951)					23 (5)	5 (1)					28 (6)
	15B (1951)					48 (11)	6 (1)		4 (1)			58 (13)
17A	11D (1947)					4 (1)						4 (1)
	14D (1950)					5 (1)			4 (1)			9 (2)
	14E (1950)								10 (2)			10 (2)
	15C (1951)					18 (4)	6 (1)		22 (6)			46 (11)
	15D (1951)						5 (1)	26 (1)	17 (4)			48 (6)
17B	14G (1950)								8 (2)			8 (2)
	14H (1950)								12 (3)			12 (3)
	15E (1951)								22 (6)			22 (6)
18	10A (1946)								4 (1)			4 (1)
	13F (1949)						5 (1)		4 (1)			9 (2)
	15F (1951)						13 (2)		129 (32)			142 (34)
	15G (1951)						6 (1)		29 (8)			35 (9)
20	15DD (1951)						24 (4)		39 (9)			63 (13)
	15EE (1951)						19 (3)	26 (1)	11 (3)			56 (7)
23	13H (1949)									32 (1)		32 (1)
	14L (1950)					4 (1)						4 (1)
	14M (1950)									32 (1)		32 (1)
	15H (1951)									96 (3)		96 (3)
24	15M (1951)								5 (1)			5 (1)
	15N (1951)									32 (1)		32 (1)
25	13M (1949)			70 (1)								70 (1)
	15Q (1951)								4 (1)	32 (1)		36 (2)
	15R (1951)								5 (1)			5 (1)
	15S (1951)										102 (1)	102 (1)
26	14V (1950)										307 (3)	307 (3)
	14W (1950)										307 (3)	307 (3)
27	14X (1950)										102 (1)	102 (1)
	Totals	717 (50)	1,257 (10)	1,444 (23)	3 (1)	152 (34)	94 (16)	78 (3)	336 (84)	256 (8)	818 (8)	5,155 (237)

[1] Nine tags recovered at Seal Cove are not included in table. Seven Area 6 tags (one 14AA, one 14BB, and five 15V) and one Area 7 tag (15AA) were recovered from Area 6; one Area 10 tag (14EE) was recovered from Area 7.

Table III.—Number of Tags Recovered by Plant Crews, According to Area of Tagging and Probable Sub-district of Recovery, for the 1951–52 Fishing Season

Tagging Area	Tagging Code	Probable Sub-district of Recovery							Total
		Northern	Central	Upper East Coast	Middle East Coast	Lower East Coast	West Coast	?	
4	15T (1951)	219	16	—	—	—	1	19	255
	15U (1951)	136	4	—	—	—	—	21	161
5	9P (1945)	1	—	—	—	—	—	—	1
	9Q (1945)	—	1	—	—	—	—	—	1
	14CC (1950)	26	3	—	—	—	—	4	33
6	9N (1945)	1	—	—	—	—	—	—	1
	14AA (1950)	8	94	—	—	—	1	2	105
	14BB (1950)	19	180	—	—	—	—	11	210
	14DD (1950)	7	50	—	—	—	—	7	64
	15V (1951)	28	572	—	—	—	1	207	808
	15W (1951)	38	209	—	—	—	2	13	262
7	8M (1944)	—	—	—	—	—	—	1	1
	9M (1945)	—	1	—	—	—	—	1	2
	14HH (1950)	2	51	—	—	—	—	1	54
	14KK (1950)	2	91	—	1	—	—	10	104
	15X (1951)	3	220	—	1	—	—	32	256
	15AA (1951)	3	346	1	—	—	2	121	473
	15BB (1951)	—	272	—	—	—	—	9	281
10	9K (1945)	—	2	—	—	—	—	—	2
	14EE (1950)	—	11	—	—	—	—	1	12
	15CC (1951)	1	44	2	3	—	2	9	61
12	9G (1945)	—	—	—	—	—	1	—	1
	9H (1945)	—	—	—	—	—	—	1	1
	9J (1945)	—	—	1	—	—	—	—	1
	10H (1946)	—	—	3	—	—	—	—	3
15	13A (1949)	—	—	—	5	1	—	—	6
	14B (1950)	—	—	—	9	—	—	4	13
	14C (1950)	1	1	1	9	—	—	5	17
	15A (1951)	—	—	1	15	2	—	4	22
	15B (1951)	—	1	—	39	3	—	12	55
17A	9C (1945)	—	—	—	—	—	1	—	1
	13C (1949)	—	—	—	—	1	1	—	2
	14A (1950)	—	1	—	3	—	—	1	5
	14D (1950)	—	—	—	—	1	—	—	1
	14E (1950)	—	—	—	—	4	1	—	5
	14F (1950)	—	—	—	—	1	—	—	1
	15C (1951)	—	—	—	1	27	—	7	35
	15D (1951)	—	—	—	—	11	—	3	14
	15L (1951)	—	—	—	—	—	—	1	1
17B	9B (1945)	—	—	—	—	—	1	—	1
	14G (1950)	—	—	—	—	5	1	—	6
	14H (1950)	—	—	—	—	8	—	6	14
	15E (1951)	—	—	—	—	7	2	1	10
18	13E (1949)	—	—	—	—	3	1	1	5
	13F (1949)	—	—	—	—	5	1	1	7
	15F (1951)	—	—	—	2	42	1	9	54
	15G (1951)	—	—	—	1	17	1	1	20
20	15DD (1951)	—	—	—	—	20	—	4	24
	15EE (1951)	—	—	—	—	10	2	—	12
23	11F (1947)	—	—	—	—	—	—	1	1
	11H (1947)	—	—	—	—	—	2	—	2
	11J (1947)	—	—	—	—	—	1	—	1
	11K (1947)	—	—	—	—	—	3	—	3
	11M (1947)	—	—	—	—	—	2	—	2
	12G (1948)	—	—	—	—	—	1	—	1
	12H (1948)	—	—	—	—	—	1	—	1
	12I (1948)	—	—	—	—	—	2	—	2
	12J (1948)	—	—	—	—	—	3	—	3

Table III.—Number of Tags Recovered by Plant Crews, According to Area of Tagging and Probable Sub-district of Recovery, for the 1951–52 Fishing Season—Continued

Tagging Area	Tagging Code	Probable Sub-district of Recovery							Total
		Northern	Central	Upper East Coast	Middle East Coast	Lower East Coast	West Coast	?	
23	12K (1948)	—	—	—	—	—	3	—	3
	13G (1949)	—	—	—	—	—	3	—	3
	13H (1949)	—	—	—	—	—	11	1	12
	13I (1949)	—	—	—	—	—	9	—	9
	14I (1950)	—	—	—	—	—	9	2	11
	14K (1950)	—	—	—	—	—	4	—	4
	14L (1950)	—	—	—	—	—	14	—	14
	14M (1950)	—	—	—	—	—	6	2	8
	15H (1951)	—	—	—	—	—	59	1	60
	15K (1951)	—	—	—	—	—	5	—	5
	15L (1951)	—	—	—	—	—	—	1	1
24	11P (1947)	—	—	—	—	—	1	—	1
	12L (1948)	—	—	—	—	—	2	—	2
	12M (1948)	—	—	—	—	—	8	1	9
	13K (1949)	—	—	—	—	—	4	—	4
	13L (1949)	—	1	—	—	—	16	—	17
	14N (1950)	—	—	—	—	—	10	1	11
	15M (1951)	—	—	—	—	—	10	1	11
	15N (1951)	—	—	—	—	—	45	2	47
25	10P (1946)	—	—	—	—	—	1	—	1
	11F (1947)	—	—	—	—	—	1	—	1
	11R (1947)	—	—	—	—	—	1	1	2
	11W (1947)	—	—	—	—	—	6	—	6
	11X (1947)	—	—	—	—	—	1	—	1
	12N (1948)	—	—	—	—	—	5	—	5
	12Q (1948)	—	—	—	—	—	6	—	6
	12R (1948)	—	—	—	—	—	2	—	2
	12S (1948)	—	—	—	—	—	6	1	7
	13M (1949)	—	—	—	—	—	21	—	21
	13P (1949)	—	—	—	—	—	5	—	5
	13Q (1949)	—	—	—	—	—	8	—	8
	13R (1949)	—	—	—	—	—	7	1	8
	13S (1949)	1	—	—	—	—	39	—	40
	14P (1950)	—	—	—	—	—	1	—	1
	14Q (1950)	—	—	—	—	—	23	—	23
	14R (1950)	1	—	—	—	—	7	1	9
	14S (1950)	1	—	—	—	—	7	1	9
	14T (1950)	—	—	—	—	—	45	1	46
	14U (1950)	—	—	—	—	—	22	2	24
	15P (1951)	—	—	—	—	—	43	6	49
	15Q (1951)	—	—	—	—	—	89	5	94
	15R (1951)	—	—	—	—	—	52	2	54
	15S (1951)	—	—	—	—	—	77	3	80
26	10Q (1946)	—	—	—	—	—	1	—	1
	12T (1948)	—	—	—	—	—	11	1	12
	12U (1948)	—	1	—	—	—	1	1	3
	14V (1950)	1	—	—	—	—	101	9	111
	14W (1950)	1	—	—	—	—	86	10	97
27	12W (1948)	—					2	—	2
	12X (1948)	—	—	—	—	—	9	1	10
	14X (1950)	—	7	—	—	—	28	7	42
	Totals	500	2,179	9	89	168	971	596	4,512

Table IV.—Average Percentage Age Composition of Samples from Commercial Catches and from Spawning Runs during the 1951–52 Season

COMMERCIAL CATCHES

Area	Number of Samples	In Year of Age								
		I	II	III	IV	V	VI	VII	VIII	IX
23	16	0.06	5.29	66.06	19.83	7.88	0.75	0.13	—	—
24	1	—	4.00	60.00	24.00	9.00	2.00	1.00	—	—
25	37	—	0.19	10.11	27.23	52.54	7.32	2.12	0.42	0.05
All	54	0.03	2.55	36.18	23.87	31.64	4.27	1.21	0.22	0.03

SPAWNING RUNS

23	5	—	16.48	70.20	9.60	2.27	1.02	0.42	—	—
24	2	—	9.91	63.97	18.27	5.74	1.58	0.52	—	—
25	1	—	2.06	27.84	21.65	39.18	4.12	5.15	—	—
26	1	—	28.42	57.89	9.47	4.21	—	—	—	—
All	9	—	14.74	62.74	12.85	7.36	1.38	0.92	—	—

Table V.—Average Sex Ratio (Females—Males) and Stage of Development for Samples of Commercial Catches and Spawning Runs during the 1951–52 Season

COMMERCIAL CATCHES

Area	Sex Ratio	Percentage		
		Immature	Mature, Unspent	Mature, Spent
23	1.10	7.6	92.4	—
24	0.47	4.0	96.0	—
25	1.02	—	99.3	0.7
All	1.03	2.5	97.0	0.5

SPAWNING RUNS

23	0.64	1.4	44.8	53.8
24	0.80	—	85.5	14.5
25	1.17	—	72.0	28.0
26	0.47	—	100.0	—
All	0.70	0.8	51.9	47.3

Table VI.—Average Length (Millimetres) and Average Weight (Grams) for Each Age in Samples from Commercial Catches, with Numbers of Fish on Which Averages Are Based in Parentheses.

AVERAGE LENGTH

In Year of Age	Area 23	Area 24	Area 25	All Areas
I	(1) 131.0			(1) 131.0
II	(84) 158.5	(4) 156.8	(7) 167.1	(95) 159.1
III	(1,047) 186.3	(60) 184.2	(329) 191.2	(1,436) 187.3
IV	(315) 198.4	(24) 198.5	(891) 207.4	(1,230) 204.9
V	(125) 212.7	(9) 205.6	(1,693) 217.5	(1,827) 217.1
VI	(12) 221.1	(2) 221.5	(230) 226.0	(244) 225.7
VII	(2) 220.0	(1) 237.0	(70) 231.8	(73) 231.6
VIII			(15) 236.5	(15) 236.5
IX			(2) 240.0	(2) 240.0
?	(14) 192.5		(76) 216.4	(90) 212.7

AVERAGE WEIGHT

I	(1) 30.0			(1) 30.0
II	(84) 52.6	(4) 51.2	(7) 57.0	(95) 52.9
III	(1,047) 89.6	(60) 89.5	(255) 89.5	(1,362) 89.6
IV	(315) 108.7	(24) 109.3	(683) 117.1	(1,022) 114.4
V	(125) 139.3	(9) 132.0	(1,251) 138.5	(1,385) 138.5
VI	(12) 161.3	(2) 150.0	(168) 156.5	(182) 156.7
VII	(2) 161.0	(1) 188.0	(50) 169.7	(53) 169.7
VIII			(14) 179.5	(14) 179.5
IX			(2) 190.0	(2) 190.0
?	(14) 94.1		(60) 131.7	(74) 124.6

Table VII.—Average Length (Millimetres) in Samples from Spawning Runs, with Numbers of Fish on Which Averages Are Based Indicated in Parentheses

In Year of Age	Area 23	Area 24	Area 25	Area 26	All Areas
II	(77) 166.1	(19) 161.4	(2) 171.5	(27) 166.6	(125) 165.6
III	(332) 186.0	(123) 187.8	(27) 187.8	(55) 190.8	(537) 187.0
IV	(46) 201.4	(35) 202.9	(21) 207.7	(9) 204.2	(111) 203.3
V	(11) 215.4	(11) 216.3	(38) 220.0	(4) 218.7	(64) 218.5
VI	(5) 222.2	(3) 214.7	(4) 228.3		(12) 222.3
VII	(2) 229.5	(1) 230.0	(5) 231.4		(8) 230.8
?	(27) 181.0	(8) 194.1	(3) 210.3	(5) 193.0	(43) 186.9

VICTORIA, B.C.
Printed by DON MCDIARMID, Printer to the Queen's Most Excellent Majesty
1953

1,200-1252 9034

Seventh Pacific Science Congress, Vol. III, 1952

REVIEW OF CANADIAN PACIFIC OCEANOGRAPHY SINCE 1938

By JOHN P. TULLY, Pacific Biological Station, Nanaimo

INTRODUCTION

Until 1943 oceanography on the Pacific Coast was sponsored by the Fisheries Research Board, and was directed entirely to fisheries objectives. From then until 1947 the facilities were diverted to naval purposes under the direction of the National Research Council. In 1946 the Joint Committee on Oceanography was formed by pooling the requirements and allotments of the Fisheries, Navy, and National Research Council in this field of research. Atlantic and Pacific Oceanographic Groups are established with headquarters at the respective biological stations, and vessels manned and operated by the Navy. Technical assistance and equipment is provided by the National Research Council. This interdepartmental co-operation has greatly increased the horizon and capabilities of Canadian oceanographic research.

H M C.S. "CEDARWOOD," A CANADIAN OCEANOGRAPHIC RESEARCH SHIP

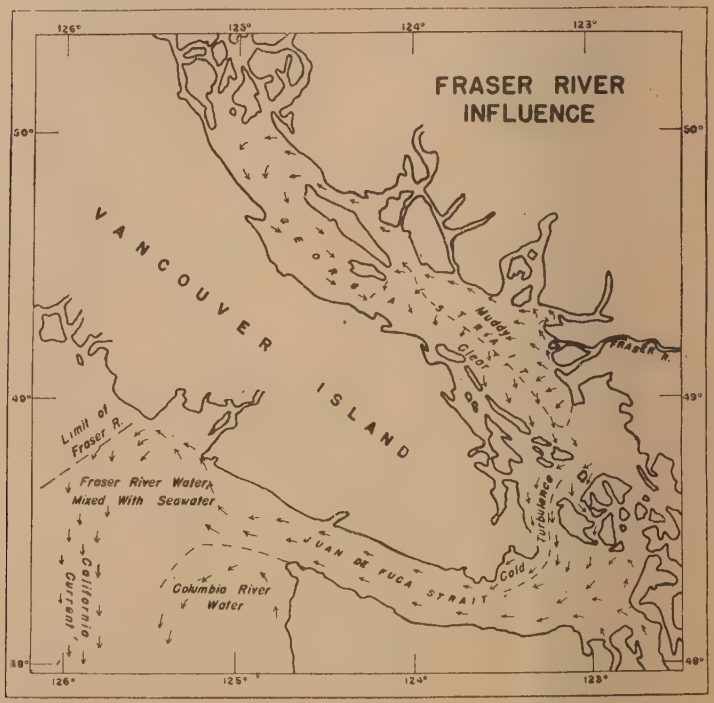
To date most Canadian oceanographic studies in the Pacific have been located in the coastal regions and the inland seaways, and in consequence have been primarily concerned with the influence of fresh water in the sea, and related phenomena.

The Fraser River Project

The influence and limits of the Fraser River in the sea has been the subject of investigation by Canadian and United States oceanographers for the past twenty years. These include the studies by the University of British Columbia, the University of Washington, the Pacific Biological Station, and the Canadian Navy. These data are being consolidated into a coherent digest by the Oceanographic Laboratories at the University of Washington and the Pacific Oceanographic Group.

The Fraser River outflow system contains one of the wealthier fisheries of the Pacific coast, and is the subject of considerable fisheries research. Further, the system provides a wide variety of oceanographic conditions with virtual temperature gradients representative of Arctic, Temperate, and Tropical seas. As such, it is of primary importance as a region for naval underwater research.

It was found that the Fraser River spreads out in Georgia Strait, most of the water moving anti-clockwise around that basin, mixing with the underlying sea-water *en route*. It passes to the sea, through a



Fraser River Influence

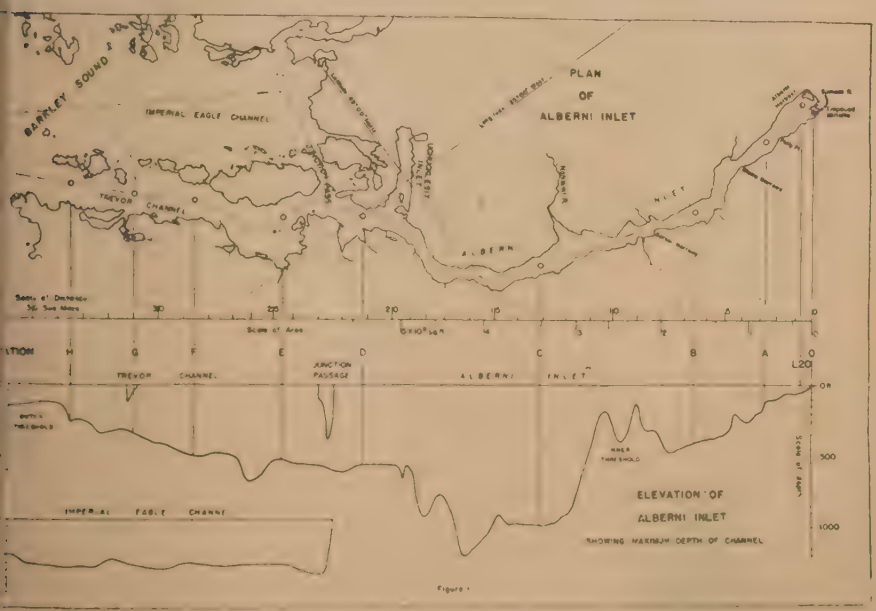
region of extreme turbulence in the Washington Archipelago, where the 30 ft. to 40 ft. depth of brackish surface water, originating in the Fraser River outflow, becomes mixed with about 600 ft. of dense sea-water, provided by tidal circulation from the zone of up-welling along the ocean coast. Evidence of fresh water from the Fraser River is lost in this process, so that the outflow from Juan de Fuca Strait is more saline than the approaches to many of the smaller drainage systems in the vicinity.

The outflow from Juan de Fuca Strait is evidently maintained by a hydraulic head established in Georgia Strait and Puget Sound. Emerging from the strait it veers to the right and moves northwestward along the Vancouver Island shore. This stream is subject to annual variation related to the fresh-water discharge from the Fraser River and the seasonal winds, which are south-east in the winter and north-west in the summer. Within a distance of approximately 30 miles the energy of the northwestward flow is dissipated in eddies, the water is absorbed into the California current off-shore, and moves southward in the Oceanic circulation.

This research was interrupted by the Alberni project (see below) and the war. Preparation of the report for publication is now under way.

The Alberni Project

In 1939 it was required to predict the state of pollution that would result from a proposed sulphite-pulp mill to be established at the head of Alberni Inlet on the west coast of Vancover Island. This seaway is typical of many of the "fjord type" inlets along the British Columbia and Alaska coast, which, oceanographically speaking, are two-dimensional estuary systems.



Plan and Elevation of Alberni Inlet

It was apparent that the only pollution character of consequence was the oxygen demand of the waste sulphite liquor. If pollution was to be avoided it was necessary that the mill sewage should be displaced from the mill-site to the open sea before the dissolved oxygen content of the inlet waters was lowered by 50 per cent.

An intensive oceanographic investigation showed that the fresh water from land drainage moved isostatically seaward. Due to tidal energy it mixed with the under-lying sea-water *en route* to form a brackish upper zone. The thickness, properties, and the rate of seaward displacement of water through this zone were quantitatively related to the discharge of the principal river in the inlet. There is a converse movement of ocean water in the zone immediately below this, which provides the sea-water to be mixed into the upper zone. Any fresh water transferred downwards is held isostatically adjacent to the boundary and preferentially returned to the upper zone in the mixing process. Consequently all fresh water leaves the inlet by way of the upper zone, and none accumulates in the lower.

Below the level of the threshold there is a deep zone, in which movement is generated by frictional transfer of velocity from the overlying middle zone.

A hydraulic model of the head of the inlet was built, in which the tide, the fresh and sea-water, and the winds were represented. From this it was learned that the outflow of the river was a jet function, whose stream diverged until it occupied the whole width of the inlet. Seaward of this limit of divergence there was no transverse salinity gradient, and the system was effectively two-dimensional. The tidal and isostatic flow characteristics in the head of the inlet, and the course of the effluent from various sewer outlets were studied in this model, and confirmed by oceanographic observations and float experiments in nature.

From these studies it was evident that if the pulp-mill sewage were diluted with all the wash water from the mill so that it entered the upper zone of the inlet at approximately the density of fresh water it would remain in the upper zone and be continually displaced seaward. This approach to the problem permitted the fresh water in the inlet to be regarded as a tracing solution, indicating the behaviour of the proposed effluent. It was concluded that no sewage would appear in the middle or deep zones, which would therefore be free of pollution. If sewage were dumped in these zones it would accumulate and eventually cause pollution.

The degree of pollution (P) was defined as the ratio of oxygen demand of the pulp-mill sewage (BOD) to the dissolved oxygen supply (DO). The tolerable rate of discharge of sewage into the upper zone was arbitrarily defined as the amount whose oxygen demand would not exceed 50 per cent. of the oxygen supply. The pollution was considered tolerable when

$$P = \frac{BOD}{0{\cdot}5\ (DO)} \leq 1$$

This provided a quantitative definition of pollution which could be evaluated.

The normal oxygen content of the incoming fresh and sea-water was observed, and the oxygen supply in the upper zone was evaluated from the observed proportions of each, and their rate of displacement through the inlet. The oxygen demand of the pulp-mill sewage was estimated

from the known rate of oxidation of waste sulphite liquor and its concentration and age at successive intervals between the head and mouth of the inlet. The latter quantities were predicted from the relations between river flow and the quantities of sewage discharge, the proportion of fresh water in the upper zone, and the displacement.

It was concluded that the sulphite mill would be tolerable while the discharge of the principal river into Alberni Inlet exceeded 1,600 cubic feet per second. The discharge was less than this during three months of the year, implying that mill operation would have to be curtailed, the sewage stored over the period, or the river discharge maintained by storing water when the river was high. Industry solved the problem by building a *sulphate* mill whose pollution potential was within the tolerable limits of the seaway.

The Bloedel, Stewart, and Welch Sulphate Pulp Mill at the Head of the Alberni Inlet

Legend :

A. Pulp-mill buildings.
B. Sewer outlet.
C. Settling pond (Lupsi Cupsi Point).
D. Overflow to log pond.
E. Log pond.
F. Sawmill.
G. Somass River mouth.

This installation has been checked, and the degree of pollution is found to be well within the predicted limits. At the same time further expansion is limited by the remaining margin of tolerance between the existing and limiting degree of pollution.

It is to be remarked that in this case there was no problem arising from pulp fibres settling out, because the bottom of Alberni Inlet does not contribute to a commercial fishery.

This research is unique in that it undertakes to evaluate quantitatively the characteristics of an estuarial seaway in terms of river discharge, which is a readily observable monitoring factor. It provides a quantitative measure of pollution and shows how it may be evaluated from a knowledge of the properties of the pollulant, and the oceanography of the system. Finally, it offers a precedent for the prediction of the probable degree of pollution from industrial development, which in turn permitted adjustments to be made before the fishery was damaged.

The field-work was done between 1939 and 1942, but development of the data was interrupted by the war and was only completed in 1948. The research is reviewed in detail in three papers, which are to be published as a bulletin of the Fisheries Research Board of Canada (Ottawa) :—

(1) Oceanography of Alberni Inlet, J. P. Tully.
(2) Prediction of Pulp Mill Pollution in Alberni Inlet. J. P. Tully.
(3) A Hydraulic Model of Alberni Harbour. J. P. Tully, H. J. Hollister, R. L. Fjarlie, and W. Anderson.

British Columbia

Chatham Project

At the present time the Pacific Biological Station is making an intensive investigation of the sock-eye salmon fishery associated with the Nass and Skeena Rivers. These are large rivers (2,500 to 250,000 cubic feet per second discharge) entering the inland seaway (Chatham Sound) near the boundary between British Columbia and south-eastern Alaska. A proportion of the salmon fishery occurs in Chatham Sound beyond the geographic limits of either river. An intelligent study of the fishery in the sound requires a knowledge of the influence and variations of the river in that area. The oceanographic problem is to determine the course and influence of these two rivers in the region, from the time of maximum river discharge (May) to the minimum (September) and the variations introduced by the prevailing winds and tidal cycle.

The field investigation has continued from 10th May to 10th September, and a preliminary report is in preparation.

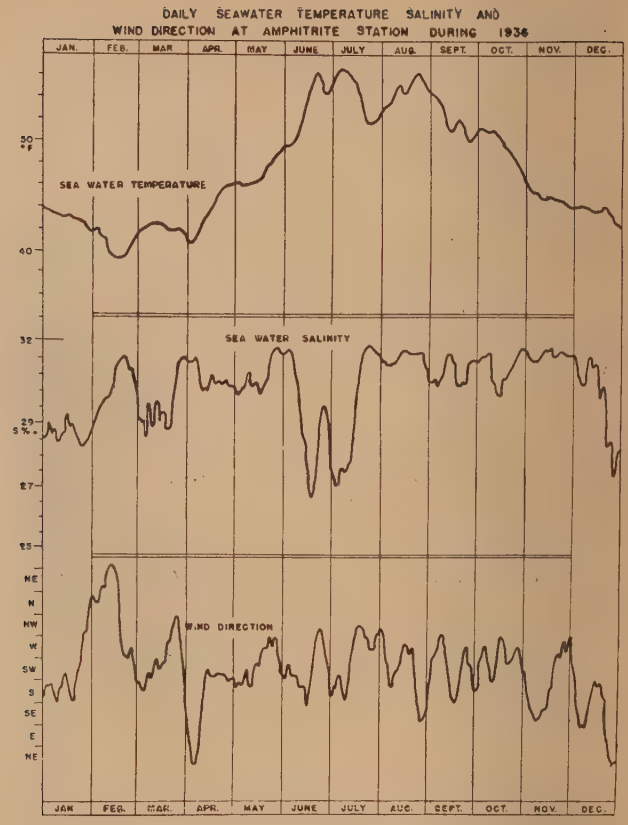
Lighthouse Project

A programme of daily observations of the sea-water temperatures and salinities was initiated on the Pacific coast of Canada in 1917 with one station. This has been increased at intervals, until the present total of eleven stations was reached in 1939. Most of the observations are made from coastal lighthouses, which explains the project designation.

The seasons are shown in the temperature data, and the integral effects of land drainage are shown in the salinity records. The small fluctuations are attributed to wind effects, since off-shore winds cause upwelling and a consequent decrease in temperature and increase in salinity. On-shore winds have the converse effect. The duration of any combination of conditions is indicated by corresponding steady states in the records.

Oceanographic surveys are tedious and costly undertakings which cannot be repeated indefinitely, and from which the conclusions usually are not available before the observed situation has passed. However, it may be assumed in most cases that the oceanographic state is determined by the season, weather, tide, and runoff whose integral effect is reflected in the conditions at one point in the region. Therefore oceanographic surveys are usually undertaken to observe type states in terms of the controlling factors, and the conclusions related to the appropriate lighthouse observations. This allows the recurrence of the observed state to be recognized from these data alone—that is, the lighthouse data serve to identify the conditions under which occasional oceanographic observations are made, their duration, and frequency of repetition. The daily observations provide a complete calendar of events in the coastal ocean and seaways, by which present data may be made applicable to the past and future.

It is the purpose of this investigation to accumulate these records as reference data for all other investigations in the Canadian coastal seas, to determine their significance as submarine climatological indices, to determine their relations, if any, with the success of coast fisheries, to evaluate annual cycles and trends, and geographical differences. Their use has been somewhat delayed by the War, but this process of examination is begun, and studies based on the data may be anticipated.


DAILY SEAWATER TEMPERATURE SALINITY AND
WIND DIRECTION AT AMPHITRITE STATION DURING 1936
JAN. FEB. MAR APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
50 °F
SEA WATER TEMPERATURE
40
32
SEA WATER SALINITY
29 S‰
27
25
NE N NW W SW S SE E NE
WIND DIRECTION
JAN FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.

Daily Seawater Temperature

The data are being published in mimeographed volumes which may be obtained on application to the Director, Pacific Biological Station, Nanaimo, B.C.

Observations of Sea-water Temperature, Salinity, and Density on the Pacific Coast of Canada

Volume	I: 1914 to 1934 inclusive ..	Now available.
,,	II: 1935 to 1937 inclusive ..	,,
,,	III: 1938 and 1939	,,
,,	IV: 1940 and 1941	,,
,,	V: 1942 and 1943	,,
,,	VI: 1944 and 1945	,,
,,	VII: 1946 and 1947	,,
,,	VIII: 1948 and thereafter to be issued in annual volumes.	

H.M.C.S. "Ehkoli," a Canadian Oceanographic Research Ship

R. E. Owen, Government Printer, Wellington.

NOTES ON THE BEHAVIOUR OF FRESH WATER ENTERING THE SEA

By John P. Tully, Pacific Oceanographic Group, Nanaimo, B.C., Canada

It has been observed(1, 2, 3, 4) that fresh water flowing into the sea from any river forms a layer of brackish water flowing on the normal sea-water of the region (Fig. 1).

In the upper zone of fresh-water influence the salinity increases to seaward, and with depth to an inflexion in the salinity-depth relation. The upper zone of fresh-water influence is characterized by horizontal and vertical salinity gradients that are large compared to those in the underlying normal sea-water in the lower zone or beyond the influence of the river.

In general the fresh water from the land drainage first overruns the sea-water in the river estuary where the divergence and course of the outflow is determined by the shores. Such a situation is oceanographically simple because the flow is either seaward or shoreward, depending on the tide, and there is only one source of sea-water and one of fresh water. Such systems are exemplified by estuaries, sunken river valleys, fiords, and narrow inlets(1).

When the outflow reaches the ocean, or a large seaway where it is not confined by the shore-line, the situation becomes complex because the direction of flow may vary with time, the tidal movements are not simply reversing, and there may be several sources of fresh and sea-water in any region. Complex structures and tide rips are usually found in such places.

In any case fresh water is continuously supplied from land drainage, and does not accumulate indefinitely. Therefore it is persistently displaced seaward at a rate equal to its supply. The water near the river-mouth is less dense than that to seaward. Consequently, according to Bjerknes, the gradient (solenoidal) effect tends to increase the circulation such that the surface water is accelerated seaward, and the deeper water shoreward. Since circulation of this type is present, but does not increase indefinitely, the gradient effect is balanced by the inertial (Coriolian) effect and friction. This results in the so-called gradient flow along the isobars, but does not define the displacement of water across the isobars from higher to lower pressure. However, such a flow does occur, as evidenced by the mixing of fresh and sea-water. For convenience the component of the pressure gradient which is not balanced by the Coriolian force, and results in trans-isobaric flow, may be termed the displacement head.

Evidently the effect of the Coriolian and the displacement forces must exist in any instance of flow involving fresh and sea water. In an open seaway or the ocean, where the boundaries are not restrictive, the gradient flow is large compared to displacement across the isobars, but in a simple channel the latter is the only mechanism by which stationary conditions may be maintained.

The isostatic forces could be evaluated from suitable data by simple calculations. However, the definition of a horizontal isobaric surface required for reference presents considerable difficulty, since the magnitude of the frictional forces in coastal regions cannot be accurately assessed at the present time. Furthermore, the presumption of a constant circulation over a short period of time cannot be assumed, because the continually varying tidal and run-off conditions make it doubtful if

a stationary state is ever observed in a single survey. In general it has been found most satisfactory to seek the relation between the oceanographic state and the primary factors of tide, run-off, and wind by direct observation.

Salinity Structure

In coastal regions the density structure is to a large extent a function of the salinity structure alone, the variations due to temperature differences being relatively small compared to the range of salinity involved. Then the fresh water may be regarded as a tracer solution, which may be detected by the degree of dilution with sea-water. This approach offers considerable observational advantage since the only data required are geography, tide, run-off, wind, and observations of the salinity at suitable positions and times, in relation to these factors. All other attributes such as temperature, dissolved oxygen, &c., may be regarded as properties of the mixing waters, or effects of extraneous functions, such as insolation.

Examination of a large number of vertical salinity gradients indicated that they were logarithmic (or inverse square) functions of depth (1, 2, 3, 4), each zone being marked by a continuous relation and separated from the next by a discontinuity in the curve. Heretofore this relation has been open to question because observations were always made at discreet intervals of depth with water-sampling bottles. Recently it has been possible to examine the phenomenon with a salinity-temperature-depth recorder(5), which provides a continuous record. Typical data(3) are shown on natural and logarithmic depth scales in Fig. 2.

The reasons for this mass distribution have not been satisfactorily analysed, but it appears that if the rate of mixing were constant in each zone, this form of curve would result. This would imply that all mixing functions combine within certain depth limitations to provide uniform vertical transfer. Regardless of the explanation, the universal nature of the phenomenon argues for the reliability of interpreting the salinity-depth curves as shown in the figures.

It has been observed(1, 2, 3) that the structure at any position in the zones of fresh-water influence is a function of tide, wind, and river discharge—that is, the structure recurs under like conditions and is not in general a function of time. It is well to remark that, in view of the cyclic nature of the tide, the unit of time is the tidal day.

The Simple Outflow

In a simple channel (Fig. 1) the flow is essentially two-dimensional. The transport is seaward in the upper zone, and below this sea-water may enter and leave on the tidal cycle imparting a reversing component to the system. The direction of flow is defined by the geography of the channel.

Evidently three mechanisms are involved in such a system—the seaward movement of fresh water in the upper zone due to its displacement head, the reciprocal movement in the upper and lower zones due to the hydraulic head of the tide, and the mixing of the two waters.

Tide

During the ebbing tide sea-level falls and the tendency for water to leave the channel because of this hydraulic head is the same at all levels, but is accelerated in the upper zone by the displacement flow.

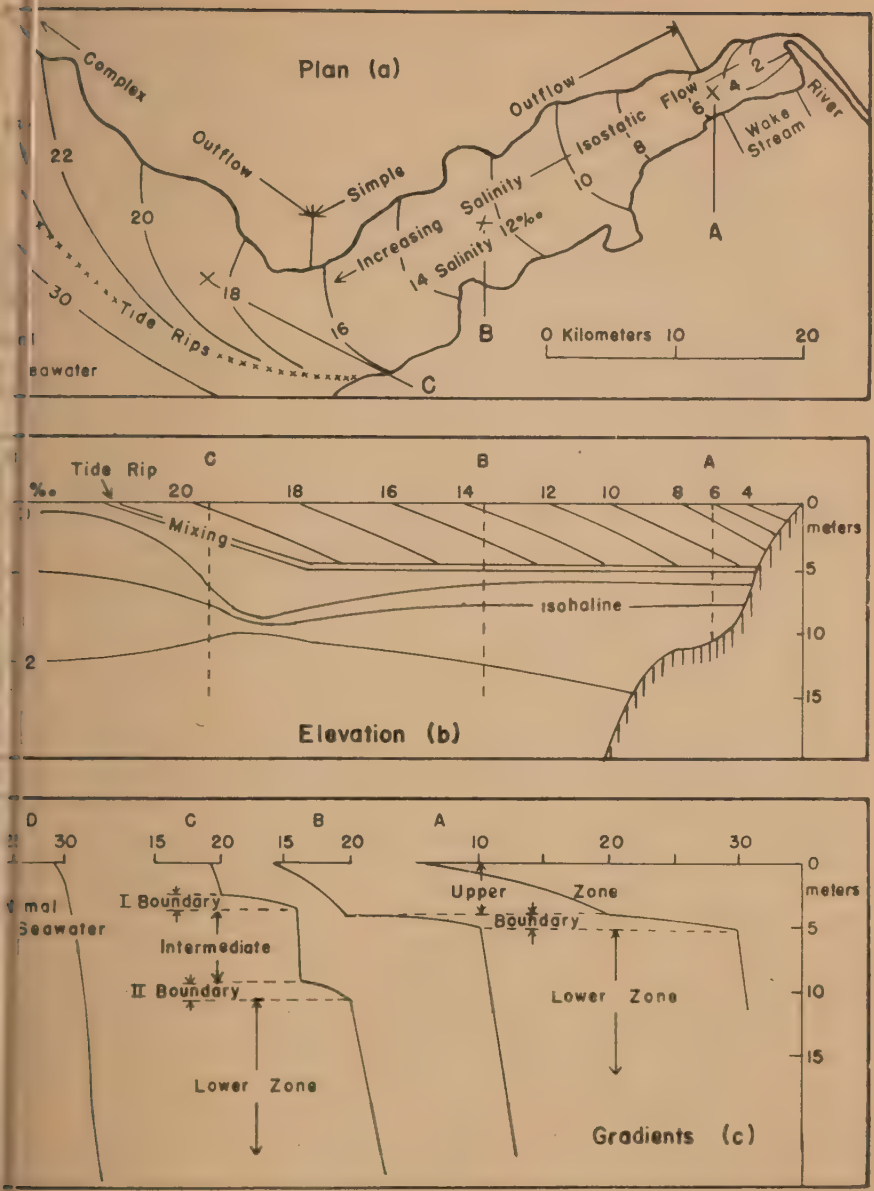


FIG. 1.—Diagrammatic illustration of salinity structure in vicinity of a northern river outflow

At low tide the tidal forces vanish, and the only flow is the seaward transport in the upper zone. As the tide rises the sea-water enters the lower zone, since its density is greater than the upper zone, and creates a flood current, which increases with the rate of tidal rise. The slack water associated with low tide occurs when the opposing tidal and displacement velocities are equal. As the tidal velocity continues to increase, the upper zone is erased to seaward and retreats into the channel. It becomes thicker, and fresh water accumulates, increasing the isostatic forces until they equal the hydraulic forces of the tide. In this situation a front separating the invading sea-water and the upper zone is formed near the mouth of the channel (Fig. 1) which progresses in-shore as the tide rises.

Eventually the isostatic and tidal forces again attain equality, due to increase of the former or decrease of the latter, and a second period of slack water occurs, associated with high tide. Thereafter the surface seaward displacement is resumed, while the flood movement in the lower zone decreases to zero at high tide.

The sea-water entering the lower zone during the flood, less the land drainage, is the volume required to make up the tidal rise. The ebb from both zones consists of the volume required by the fall of the tide, plus the land drainage during this phase.

Then during the steady state the fresh water transferred seaward through any cross-section of the channel during a tide-cycle is equal to the land drainage above the section, and equal volumes of sea-water flood and ebb through the section in a cycle. If these consequences did not obtain, fresh or sea water would accumulate over a series of cycles and the channel would become totally fresh or sea water. Obviously the considerable mixing during the process has no effect on the quantities transferred.

It is implied in this argument that surface sea-water submerges below the upper zone at the front and enters the channel in the lower zone during the flooding tide, some of it is transferred to the upper zone in the channel, and sea-water escapes from the channel by both zones during the ebb tide. It follows that, aside from the fresh water present, the movement of sea-water in the upper zone is biased in the ebb direction, while that in the lower zone is biased in the flood direction, in compensation for the sea-water transferred upwards.

Turbulence

The progressive increase of salinity in the upper zone must be the result of some mechanism of turbulence. Turbulent flow is usually exemplified in Nature by a large number of more or less coherent eddies having random compensatory motion within the fluid. This motion is opposed by friction between the elements (eddy viscosity) resulting in an exchange of fluid between the eddies and their surroundings (mixing).

In a density stratified medium any movement of the fluid elements within a stratum is opposed by viscosity alone, but any movement of the elements from one stratum to another is also opposed by isostatic forces, which tend to return the element to its own level. From this it would be expected that a stratified system would become more homogeneous down-stream, and that lateral homogeneity would be more readily attained than vertical homogeneity. This reasoning has been confirmed by observation(1) and is indicated in Fig. 1.

Reynold showed that in a wide channel the incidence of turbulence is a function of the average velocity and depth (of homogeneous layer), as shown in Table I.

TABLE I—REYNOLD NUMBER

Flow is turbulent when—

$$N_R = \frac{VD\rho}{\upsilon} = 500$$

N_R Reynold number.
V mean horizontal velocity.
D depth of channel.
ρ density of fluid.
υ kinematic viscosity.

Velocity cm./sec.	Depth. cms.
7·65	3·05
1·53	15·25
0·77	30·5
0·15	152·5

In the vicinity of an estuary the mixing between fresh and sea-water zones must be attributed to external forces such as the wind and tide, because the isostatic flow is in general less than the threshold of turbulence as defined in Reynold's experiments. Examining the discharge of several rivers(1, 2, 3) it became evident that the flow due to the dispersal of fresh water alone would cease to be turbulent at a short distance from the outfall because of the widening front of flow in the sea.

The tidal velocities in most coastal regions are adequate to cause a considerable degree of turbulence, and because they are rotary or reversing their contribution to transport is small. In open seaways mixing due to the acceleration of the wind must also be considered, and may be assumed to be the predominant factor in the ocean, where tidal movements are small.

Obviously some degree of mixing would result from isostatic movements, but in general the mixing function is superimposed on the isostatic flow functions by extraneous forces. It is concluded that in a simple channel mixing occurs primarily at the expense of the tidal rise and fall, while the seaward transport of the water is due to the displacement head.

This was confirmed by observation in Alberni Inlet(1) where the tidal velocities attained 150 cm. secs., but the rate of net transport seaward was of the order of 0·01 to 0·06 cm./sec.

It is evident that an isostatic movement would occur whether or not there was mixing. Therefore the seaward movement of fresh water is not consequent on the rate of mixing. However, it is implied that the fresh water must move seaward at a rate equal to its supply, wherefore the stream must accelerate or diverge in proportion to its dilution with sea-water. This agrees with observations(1) which show that the velocity and mass transport in the upper zone of such systems increases to seaward, and that the dimensions of the zone is constant within certain limits of variation.

Mixing

In general, the upper and lower zone both become more saline to seaward, from which it is reasoned that all the fresh water is dispersed in the upper zone, and little or no fresh water is lost by downwards transfer. This requires some explanation, since in any process of mixing the volume of water transferred downwards must equal the volume transferred upward, else the medium would become discontinuous.

In the case of an upper zone carrying fresh water over a lower sea-water zone which moves in the same direction with the same or greater velocity, the exchanged water would be carried forward in both zones, the upper zone becoming more saline and the lower zone less saline as they approach homogeneity. However, this process would imply that the upper zone flow was in the opposite direction and of lesser magnitude than the movements in the lower zone. It does occur near the front at the mouth of the inlet and results in modifications of the simple system, which will be discussed later under "Complex Outflows."

It is more usual to find the lower sea-water zone moving in an opposing direction relative to the upper zone, in which case both layers become more saline to seaward. The sea-water transferred upwards is carried forward with increased velocity to be exchanged for more saline water down-stream. The upper-zone water transferred downwards will lag behind the surface flow, or be carried backwards in a boundary zone, in which there is a transition between the salinity of the lower and upper zones, and be preferentially subject to further mixing into the upper zone. Any fresh water accumulating in the lower zone would be isostatically unstable and would tend to join with the upper zone in the boundary layer.

The nature of the mixing process is indicated by the vertical salinity gradients. It may be assumed that there is a compensatory exchange of water across the boundary, and then to the adjacent parts of the zones. If the mixing at the boundary were more rapid than the mixing in the adjacent parts of the zones, mixed water would accumulate, and a homogeneous boundary layer would be created, as shown in Fig. 3 (*a*). This may be observed in the vicinity of a front, as will be discussed later. It is unstable since it implies a large turbulence function confined to the boundary, and normally such a function also includes the upper zone.

If the rate of mixing in the boundary equalled the rate of mixing adjacent to the boundary, the boundary zone would lose its identity in the formation of a simple gradient from the surface to the lower zone as shown in Fig. 3 (*b*). This is occasionally observed in Nature when the stability of the boundary zone becomes small.

Finally, if the mixing adjacent to the boundary were more rapid than the mixing in the boundary, the salinity gradient would be expected to be a maximum in the boundary which would be a distinct zone, as shown in Fig. 3 (*c*). This is the form of gradient commonly observed in simple situations(1, 2, 3).

The structure consequent on these processes is illustrated in Fig. 4 (*a*), where a representative series of salinity gradients are shown in relation to their position in the simple channel of Alberni Inlet(1). Figure (4) (*b*) shows the same gradients plotted on a logarithmic depth scale and superimposed on each other.

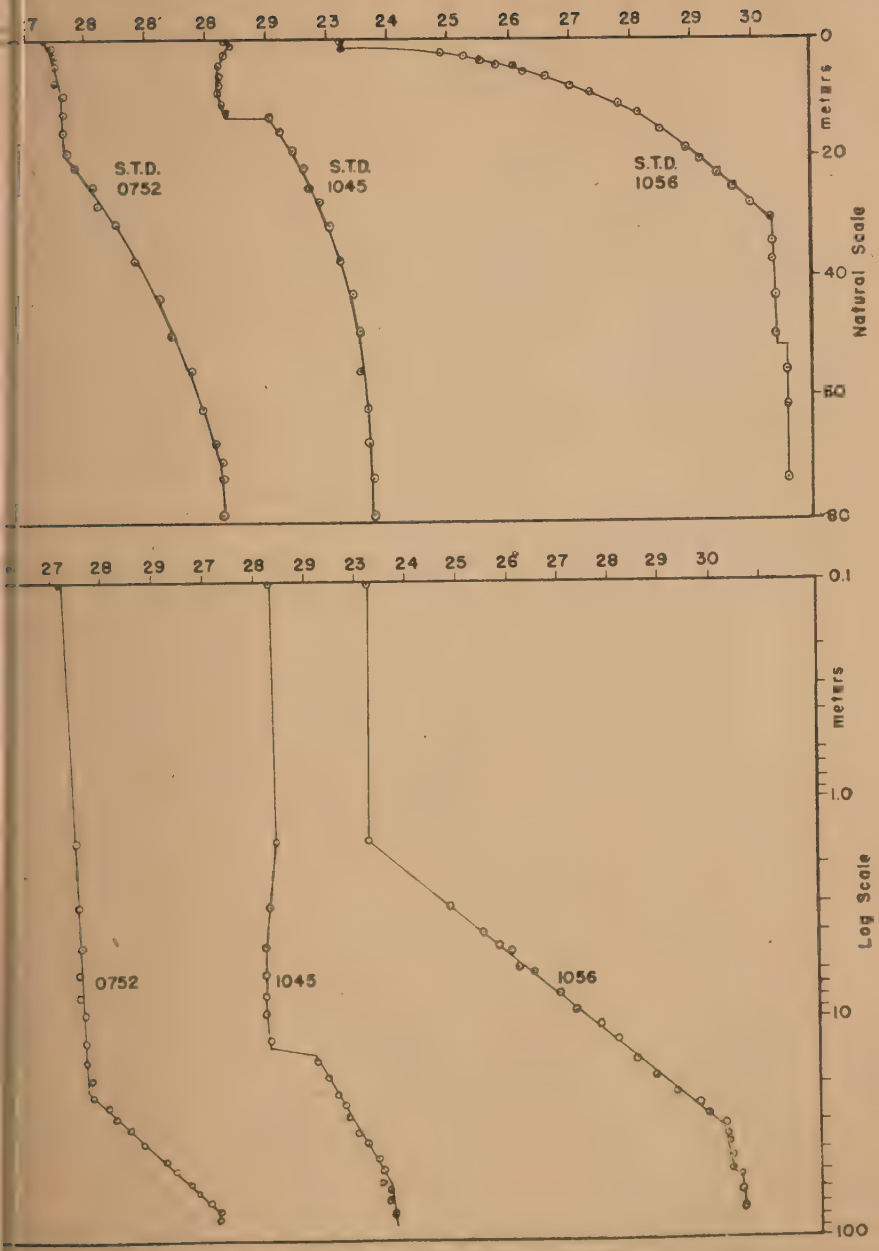


FIG. 2.—Salinity data from Georgia Strait Survey 8th December, 1943

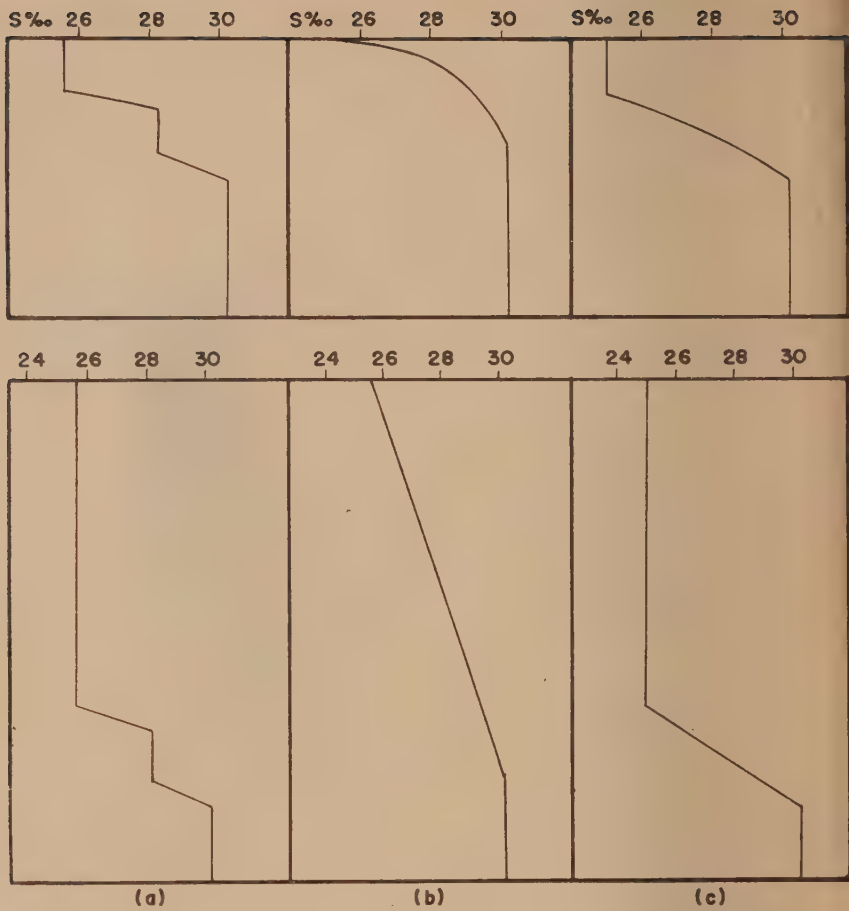


FIG. 3.—Idealized vertical salinity gradients showing type boundaries

The upper and boundary zones become progressively more saline to seaward as they degenerate to obscurity. Evidently sea-water is being transferred upwards and retained in the upper zone, and no fresh water is being transferred below the boundary. This identifies the boundary as the zone into which fresh water is transferred in the mixing process, and from which it is preferentially returned to the upper zone, along with the associated sea-water supplied from the lower zone.

From this it may be concluded that all fresh water leaves the region by way of the upper zone, and that the fresh-water influence is finally lost by infinite dilution with sea-water, when the upper zone becomes indistinguishable from the lower zone.

Evidently the upper zone is subject to two accelerations—the displacement of fresh water, which is constant through any complete cross section, and the transfer of sea-water from the lower zone. The

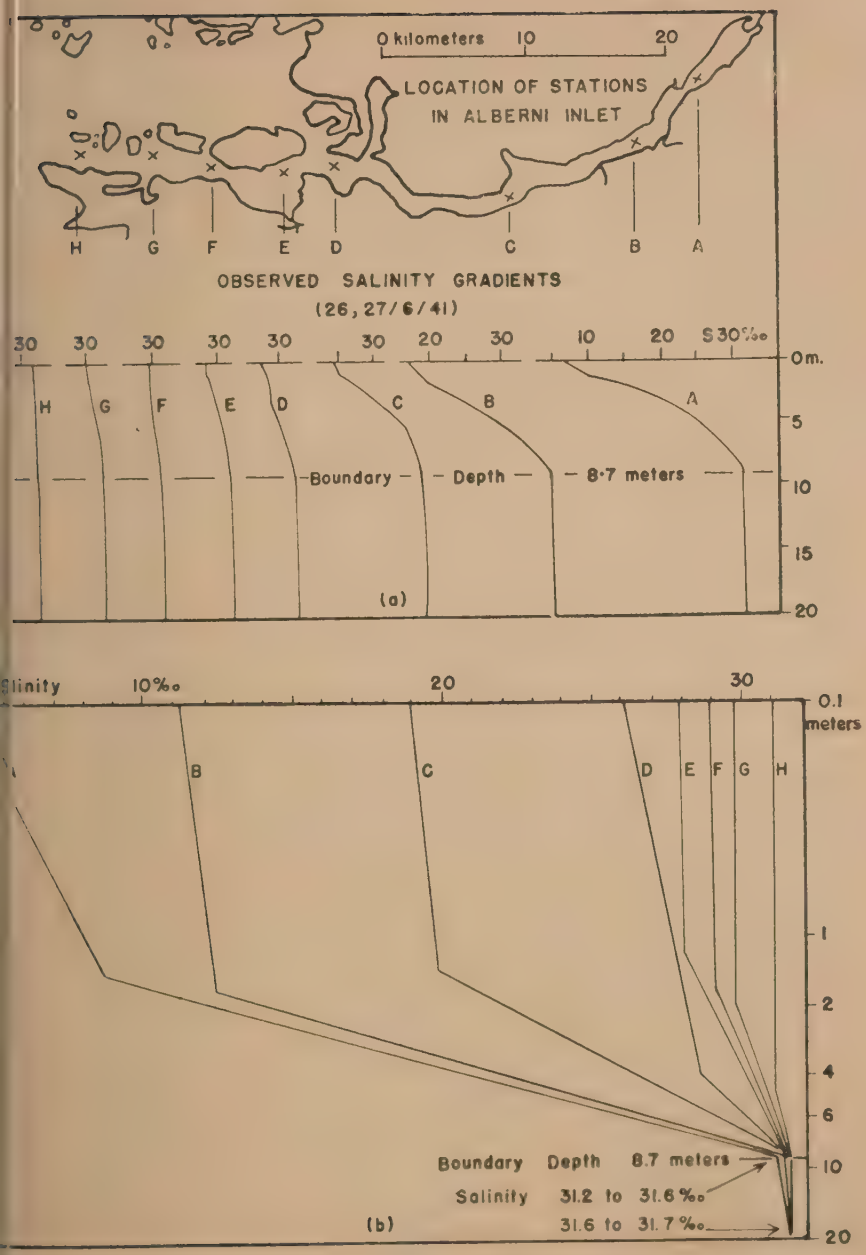


FIG. 4.—Salinity gradients, logarithmic depth scale

latter accumulates in the upper zone where the velocity increases to seaward in direct proportion to the increase of sea-water content, and inversely as the cross-section area of the upper zone.

The seaward salinity gradient originates in the turbulence function and is maintained by the displacement flow. The latter is limited to the depth of the boundary, which must therefore be a minimum potential surface and cannot be altered by forces within the system. The upper and boundary zones are everywhere less dense than the lower zone, therefore any change of level will invoke local accelerations to restore the position of minimum potential energy. The difference in level between extremes of this zone in the data cited in Fig. 4 would be of the order of 7 centimetres, which is within the limits of accuracy of the observations.

Displacement

From the preceding discussions it may be realized that at equilibrium the fresh-water outflow must be displaced seaward at a rate equal to its supply, therefore it must be possible to evaluate the seaward movements in the upper zone and the degree of mixing in terms of the discharge of the parent river.

Some proportion of the fresh and sea water in any limited region of the upper zone is displaced by like amounts entering the region in a limited time-interval. Evidently the proportion of fresh water displaced is the same as the proportion of sea-water displaced, otherwise one or other of the components would accumulate. Therefore displacement may be quantitatively defined as the proportion of water in any limited region that is replaced by new water in one complete tide-cycle. Displacement may then be evaluated from an analysis of the fresh-water distribution: consider an area (A) in which the depth of the upper zone (D) contains a proportion of fresh water (C), into which the rate of fresh water discharge is (Q) during the time of a tide-cycle (T). Then the displacement of fresh water (r) is the ratio of the volume of fresh water entering the region (QT) to the volume of fresh water already in the region (A C D)

$$r = \frac{Q\,T}{A\,C\,D}$$

This expression is exact and implies an absolute knowledge of the factors. However, when observing the natural state it is usually necessary to make interpolations and approximations in the values.

The depth of the upper zone may be determined as the intercept of the lower and boundary gradients (Fig. 4). The proportion of fresh water in the region is the ratio of the area bounded by the salinity curve, the surface, and the salinity ordinate intercepting the point defining the depth of the boundary, to the product of this salinity and depth. These quantities may be interpolated with reasonable accuracy from suitable salinity observations, and usually the runoff may be observed directly. Therefore the equation can be solved in any region where the boundaries can be defined.

Relation to Runoff

The relations of these quantities to the discharge of the parent stream are shown in Fig. 5, from the studies in the simple system in Alberni Inlet(1).

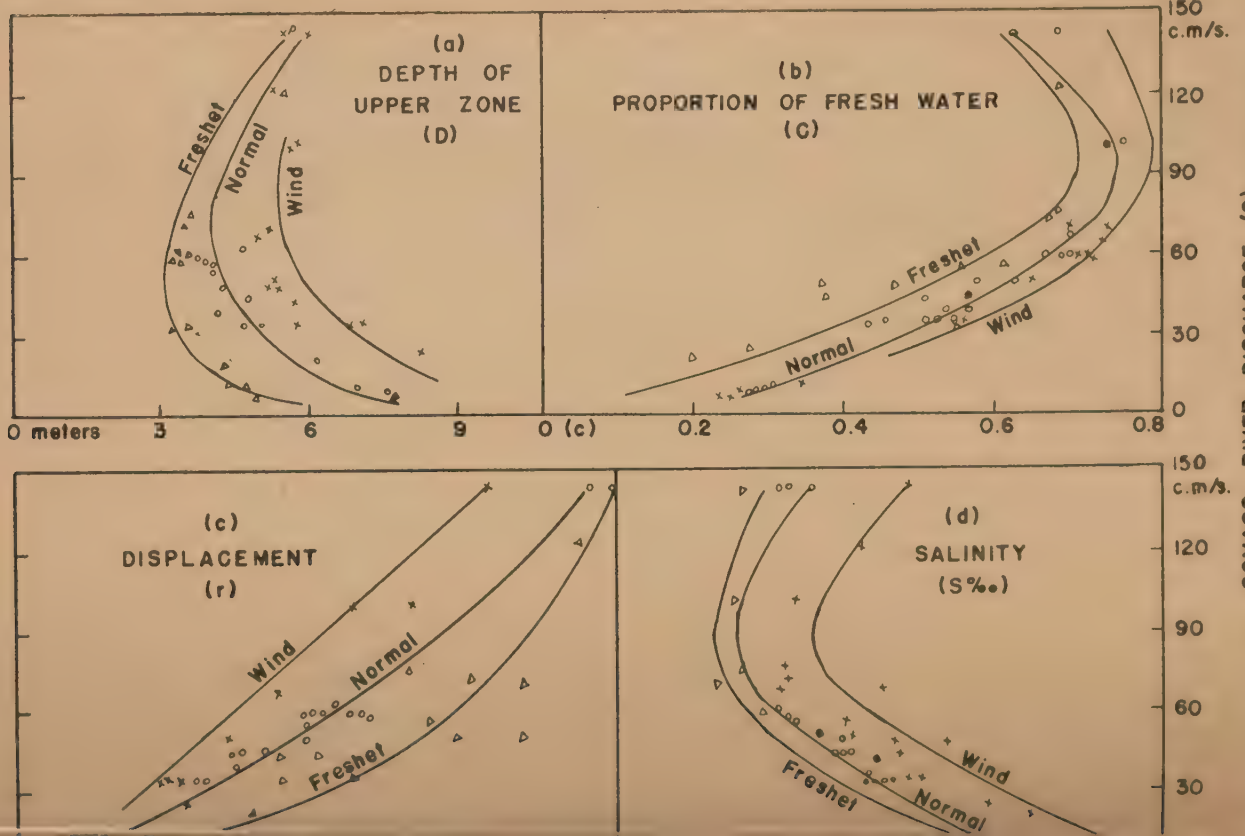


Fig. 5 Properties of the Upper Zone in Alberni Harbour related to Somass River Discharge
△ Freshet divergence.
Normal relation.
× Wind divergence.

It was found that the points were considerably more scattered from a simple relation than would be expected from variations in tidal height. The deviations in one direction were associated with increasing run-off and were designated as freshet deviation. Deviations in the other direction were associated with strong winds opposing the seaward direction of surface flow, and were referred to as wind deviation. The best line drawn through points representing steady run-off, or falling river-level, and light winds was taken to represent the normal state.

The form of the curves are remarkable. Evidently from low to intermediate discharge level, the upper zone becomes shallower and fresher, while at greater discharge it becomes deeper and more saline, although the displacement increases almost linearly. These phenomena may be interpreted with the aid of salinity gradients shown in Fig. 6 (*a*) observed during the low, intermediate, and high river discharge at a position near the head of the inlet. When land drainage is small the displacement is necessarily small, and the upper-zone water remains in the region for a considerable time so that a deep, saline upper zone is formed, as shown in the first gradient of Fig. 6 (*a*). As the run-off increases displacement increases, and the time during which the upper zone is exposed to tidal mixing in the region decreases. In consequence it becomes shallower and fresher, as indicated in the second gradient. Further increase of river discharge implies that the front between the fresh water impounded in the channel and the intruding sea-water must move further seaward. This requires increased isostatic forces, wherefore the upper zone must remain fresh and become deeper, as shown in the third gradient. This case implies considerable transport velocity, with consequent turbulence, so that the boundary gradient is thicker than in the previous case, and since it is included in the assessment of the upper zone, the salinity appears to increase.

Wind Effects

When the surface seaward flow is opposed by strong winds it would be expected that the depth of the upper zone would become greater than normal, because of the increased mixing forces, and fresh water would accumulate until the isostatic head was great enough to provide normal displacement against the restriction of the wind. This is illustrated in the sequence of group (*b*) gradients in Fig. 6. It is shown in Fig. 5 that the effect of the wind is greater when the depth of the upper zone is the least. The accumulation of fresh water in the region is shown to increase with the run-off. The effect on displacement increases to a limiting value as the boundary approaches a minimum depth, with intermediate discharge, and the surface waters are freshest. The limit is reached when the depth of the upper zone becomes great enough to permit displacement in the upper zone, below the level of wind influence.

Freshet Effects

It is apparent that the displacement must increase with run-off, but the evidence that the depth of the upper zone decreases is enlightening. This is illustrated by the sequence of gradients shown in Fig. 6 (*c*).

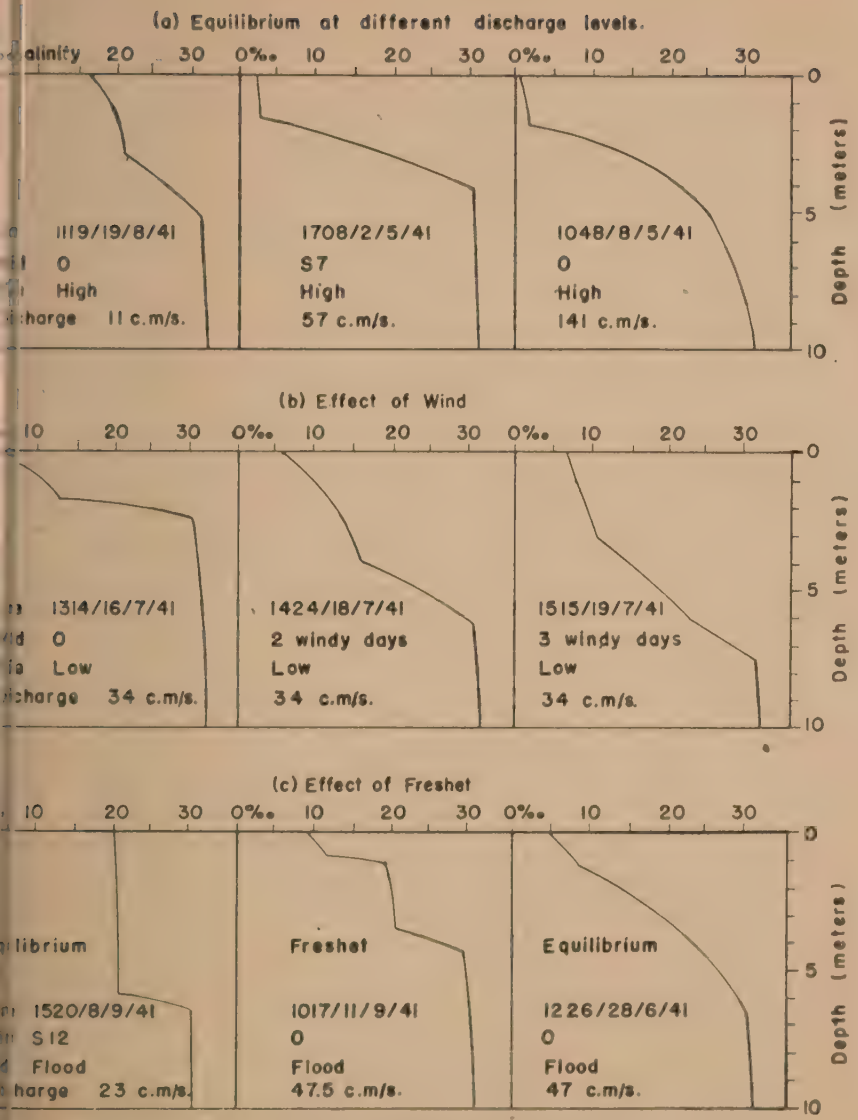


FIG. 6.—Salinity gradients in Alberni Inlet

As the displacement increases the freshet overruns the surfac repeating within the upper zone the phenomenon of the upper zon in the sea. This is shown by the transition from the first to the secon gradient. If the rise is a true freshet, of short duration, the proces ends there, and the original state is slowly re-established. Howeve if the higher discharge continues at a constant level fresh water accumu lates until a new equilibrium is established, as indicated in the thir gradient, and the boundary finds a new level.

It is concluded that a freshet has the effect of flushing the channe and produces anomalous values of depth and salinity, since it does no represent stationary conditions.

Dynamic Equilibrium

It may be concluded from these discussions that the salinit structure is recurrent within the limits of variation of wind and run-o at corresponding states of the tide-cycle. It might better be regarde as a probability, whose deviation from the normal or median stat depends on the wind and run-off history immediately before th observation.

The fresh-water content of the upper zone represents the accumulatio of fresh water required to provide the isostatic head necessary for th continuous displacement of fresh water at a rate equal to its outflo from the river. Evidently this can be accomplished in a shallow, ver fresh zone, or a deeper, more saline zone, depending on the magnitud and time of action of the extraneous mixing forces of the tide, and th wind.

The Complex Outflow

The coastal seas are subject to tidal currents(7) which are more o less rotary, so that there is no period of slack water, and there is shoreward or seaward component of flow as the tide rises or falls.

As the outflow moves seaward, whether it be radially off-shore o coastwise it will encounter an opposing tidal current on some margi and a front will be formed wherever the movements converge.

This phenomenon is illustrated diagrammatically in Fig. 7. Th fresher outflow overruns the adjacent sea-water, and forms a fronta surface which intercepts the sea surface. This frontal surface maintained by convergence towards, and a compensatory flow along, i At the "front" (the intercept of the boundary with the sea surface the horizontal convergence is balanced by a compensating vertica flow along the boundary surface. This flow consists of water contribute by both masses in proportion to the horizontal velocities normal to th front. The upper zone of the outflow may move faster than the adjacen sea-water at the surface, and so contribute more water at that leve but generally the normal velocities decrease downwards in the fresh water mass more rapidly than in the sea-water mass, and the relativ contributions to the boundary may change with depth. The water contributed by the fresh and sea-water regions are sheared off th front, mixed, and submerge to a position of isostatic stability belo the upper zone of the outflow, forming a boundary zone or, in mor extreme cases, an intermediate zone between the upper and lower zone

FIG. 7.—*Upper figures:* Concentration of fresh water (per cent.) in the upper 20 metres of Chatham Sound

Lower figures: Salinity gradients observed of lettered positions in Chatham Sound. Observations of 14–18/6/48

The situation is dynamically stable while the front is being continually renewed by a supply of water from both regions, and the mixed waters are being continually dispersed at an equal rate. Its position represents the balance where the acceleration in the tidal and isostatic flows are equal. Such regions of convergence vary from "tide lines" marked by a collection of flotsam, and/or a difference in colour of the water, to violent tide rips which may endanger small ships, depending on the velocities and magnitude of the opposing upper zones.

The synoptic charts of the concentration of fresh water shown in Fig. 7 were compiled from data observed during four days in Chatham Sound, on the Pacific Coast of Canada. The position of the tide rips in relation to the water masses indicates that they represent zones of convergence between flow across the isohalines and opposing movements in the more saline water from the adjacent sea. The salinity gradients associated with this structure were observed to be complex in almost every case, as indicated in those illustrated.

The Intermediate Zone

It is anticipated, and observations appear to show(3), that the intermediate zone associated with a front (Fig. 1 (*c*)) is usually of moderate dimensions and restricted to the vicinity of the front, because it is essentially a transitory state in the formation of a new boundary zone. The intermediate zone is evident because the mixing process at the front is proceeding faster than in the adjacent parts of the upper and lower zone, and mixed water accumulates in the boundary. This process has been illustrated in Fig. 3 (*a*) and associated discussions. As the intermediate zone is removed from the front it tends to contribute to the upper zone, and forms a simple boundary, usually at a new depth. It is implied that this metamorphosis is associated with considerable movement which is continuous with the convergence at the surface front, and has a large component parallel to it. This situation corresponds to the high tide gradients shown in Fig. 7.

The intermediate zone may also be generated when the river outflow overruns a previous discharge, which meanwhile has been considerably diluted with sea-water. This is the situation illustrated in the low-tide gradients of Fig. 7. It has been remarked that this is particularly noticeable during a freshet. It also occurs in the vicinity of a river-mouth, because of the oscillatory nature of the tide. By a combination of these functions as many as three intermediate zones have been noted(2), but it is remarked that they tend to approximate the structure of a simple boundary in which the salinity gradient is a logarithmic function of depth. These multiple intermediate zones usually occur in protected sounds or bays where the waters may be confined for some time before reaching the open sea. The data illustrated represents this combination of circumstances.

Evidently the fate of the intermediate zone in the vicinity of the outflow is to become identified with a simple boundary structure.

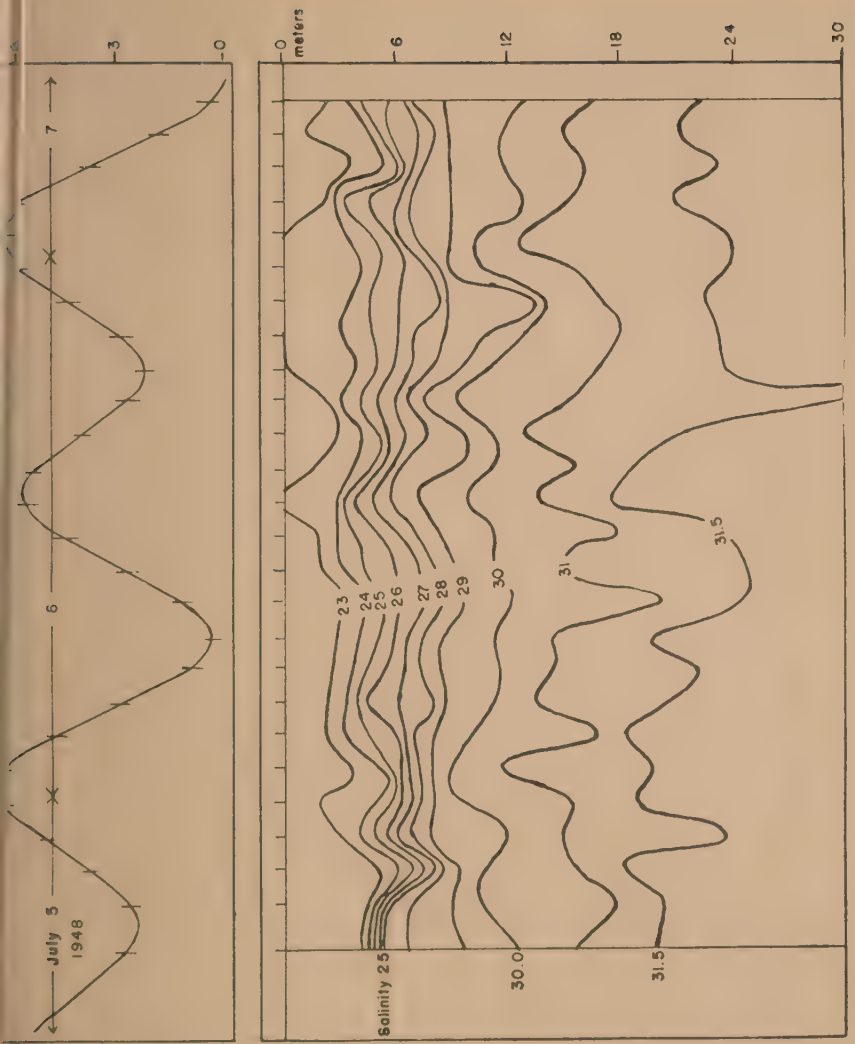


FIG. 8.—Synopsis of salinity-time profile taken at a position in an open seaway in the region of influence of a large river Position E in Fig. 7

E – Fresh Water

Discontinuous Outflow

Both the character and volume of the outflow vary with the tide. When the tide is falling, the upper zone has free egress from the estuary to the sea, since the flow in the lower zone is also seaward. During this tidal phase the upper zone tends to move rapidly away from the estuary, in a balance of gradient and displacement flow, modified by the tidal currents in the vicinity, as shown by the low tide distribution of fresh water in Fig. 7.

In the presence of rotary tides the direction of the stream may be seen to alter from time to time during the discharge. Usually it will flow in one direction for a time, and then change direction at the source quite suddenly, leaving a cloud of upper zone water isolated in the seaway.

When the tide rises sea-water usually invades the estuary, forming a front near the channel mouth, as has been described. Usually the upper-zone water discharged during the ebb has been removed from the vicinity by the local current systems, so that sea-water intrudes the estuary. This movement has the effect of cutting off the upper-zone water extruded during the previous ebb, which then floats away as a cloud. This mechanism is indicated in the high tide synoptic of Fig. 7.

When separated from their source these clouds of upper-zone water lack the isostatic forces to continue their flow and are pelagic in the surface of the seaway, where it is common to observe considerable variations of current and direction in short distances. In some circumstances the successive upper zone clouds may follow quite different courses(2). When this phenomenon is observed in the usual manner by water sampling at intervals of distance it may appear that the flow from the estuary is forked, whereas a truer interpretation would be that clouds of water are discharged alternately in the several directions.

Evidently these clouds will tend to expand radially over the sea surface under the influence of their own isostatic potential. In this case they should tend to rotate, because of the Coriolian force, and should be deepest at the centre. The formation and existence of these clouds of discharged water have been observed(9), but to present knowledge they have not been studied.

In the immediate vicinity of the outflow into a large seaway or the ocean it has been observed(2, 3, 6) that the upper-zone flow tends to follow the course that would be anticipated from dynamic topography of the sea surface. However, the upper zone appears to contain clouds of fresher water, corresponding to the discharge during successive tidal periods, since the depth and composition of the upper zone fluctuates along the line of flow. In general, the system tends to become more saline and regular with distance from the parent river.

In the simple system(1) the anticipated variation of depth of the upper zone with the tide was observed. However, in a complex system(2) the tidal variation was completely masked by a secondary variation of equal magnitude, as illustrated in Fig. 8. This apparently random variation could be explained by internal waves or by the discontinuous nature of the outflow, or possibly both. Associated data indicates that the boundary layer did oscillate in short periods, and that a cloud structure was present. This is indicated in the charts of Fig. 7, and probably explains the large variations in depth of the boundary shown in the corresponding salinity gradients.

It is apparent that the diverging outflow into a large seaway is not continuous and that any static representation can only imply an average state, about which the natural state varies. The present oceanographic instrumentation is not adequate to follow these short-period variations, even the salinity-temperature-depth recorder(5) will require some improvement before this is possible. At present it is necessary to make a series of observations at small intervals of time until enough data is collected to evaluate a reliable statistical mean of the structure. The additional time required almost vitiates the possibility of making a synoptic survey of an extensive area, where functions of tide, wind, and run-off must also be considered. It is probable that the only satisfactory approach to this problem is by model studies. A model of Alberni Harbour(11) was made in which the geography, tide, and river discharge were simulated and was successful in reproducing all the features of the outflow which have been discussed. This indicates a practical approach to the study of seaways where the boundary conditions can be represented.

The Ocean Outflow

When the outflow enters a large seaway or ocean it tends to form a jet stream(10) which veers to the right or left in response to the Coriolian force(11), at least in the middle and polar latitudes, and moves coastwise, contrary to the great ocean currents. This is more of a gradient flow along the isobars than a displacement flow across the isohalines.

Figure 9 shows an interpretation of the dynamic topography off the Pacific Coast of Canada(8) which may be regarded as representative, since the illustrated coastal current has been observed empirically, and qualitatively related with the local seasonal run-off(7) and the Japan current off-shore corresponds with what is known of this movement from casual and experimental drift observations(12).

Evidence of cloud structure in the surface waters of the open sea have been observed(14), but in general the fluctuations in properties of the water are small compared to those in the immediate vicinity of an outflow. In general, the shallow and irregular upper zones tend to obscurity in short distances because of the accelerated mixing by the considerable wind forces. Once this simplification has taken place the structure appears to be very stable and to degrade along the line of flow by a somewhat similar process to that observed in the simple system.

This is illustrated in Fig. 10, which shows a series of salinity gradients observed at regular intervals through 180 kilometres off the Pacific Coast of Canada. These stations correspond to the numbered positions in Fig. 9. They were observed while proceeding seaward on 20th July, 1936, and again during the return journey the next day, and both data are indicated in the figure.

The lower boundary is taken to mark the effective depth of wind mixing along the course of the Japan current in the open ocean, and the intermediate layer to represent the character of this water. The upper zone is shown to be continuous with the coastal system and represents the influence of local fresh water in the great ocean current.

This also implies a transfer of water across the isobars that is, there is a component of flow normal to the isohalines, corresponding to the displacement flow of the simple system. Evidently both the gradient

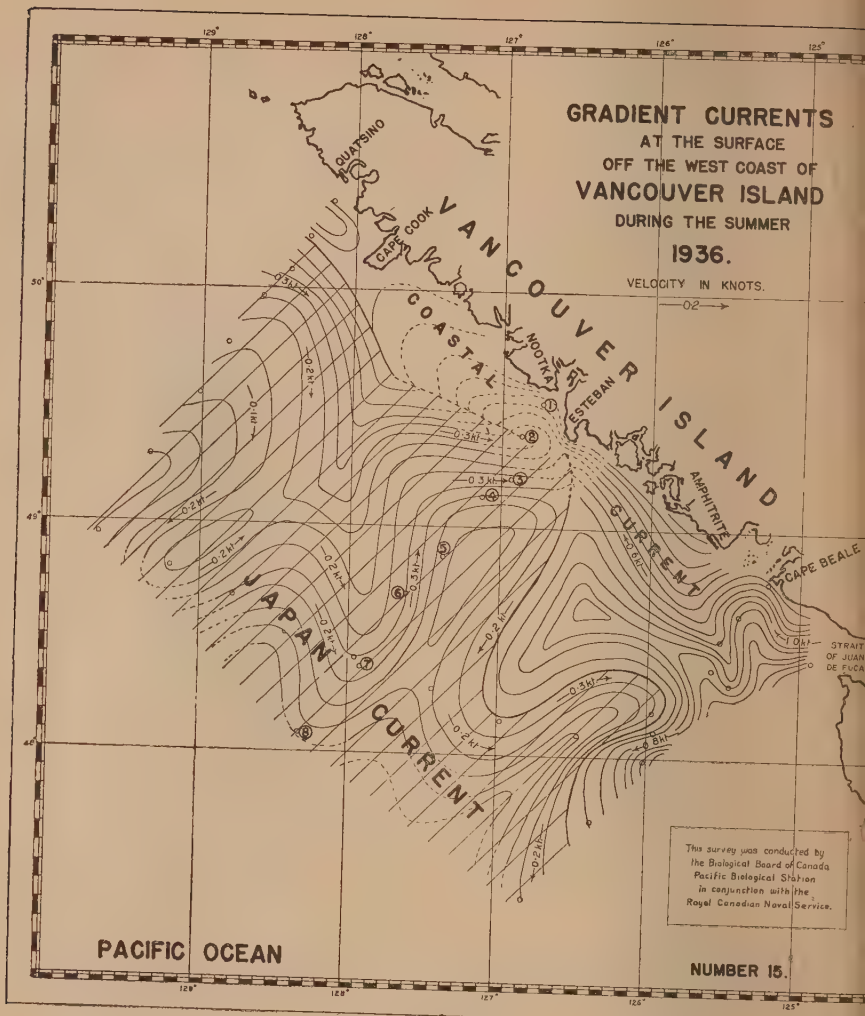

GRADIENT CURRENTS
AT THE SURFACE
OFF THE WEST COAST OF
VANCOUVER ISLAND
DURING THE SUMMER
1936.
VELOCITY IN KNOTS.
02
VANCOUVER ISLAND
QUATSINO
CAPE COOK
COASTAL
NOOTKA
ESTEBAN
AMPHITRITE
CAPE BEALE
CURRENT
JAPAN
CURRENT
PACIFIC OCEAN
This survey was conducted by the Biological Board of Canada Pacific Biological Station in conjunction with the Royal Canadian Naval Service.
NUMBER 15.

FIG. 9

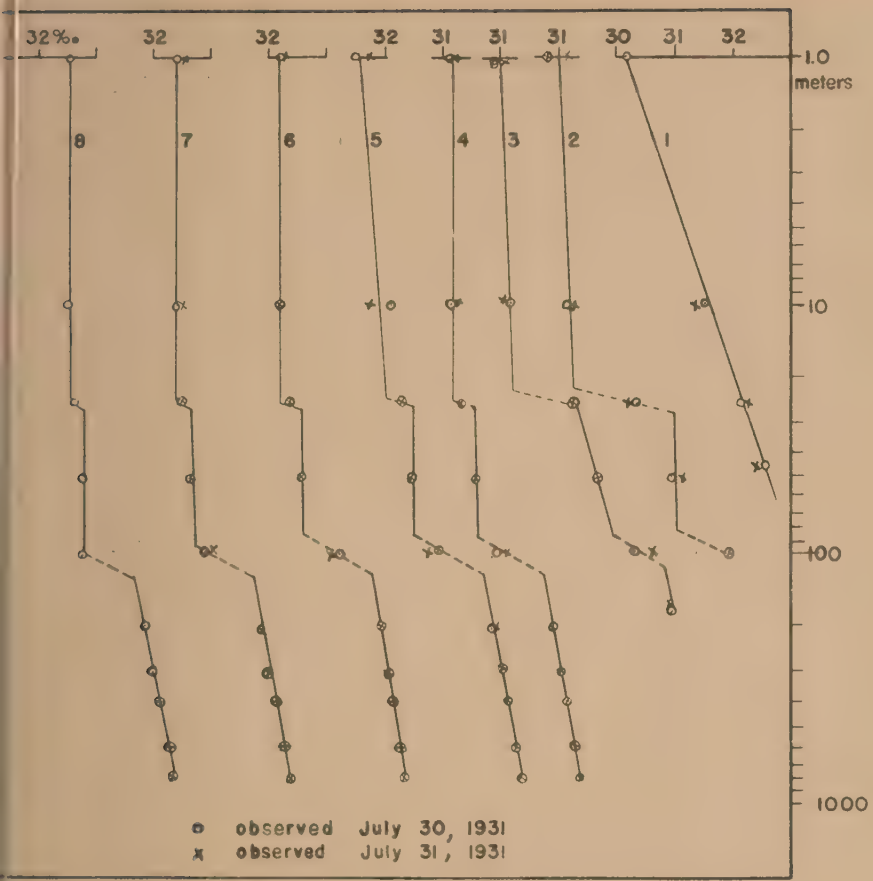


FIG. 10.—Gradients off the Pacific Coast of Canada (observed at positions marked in Fig. 9)

and displacement tendencies must continue to exist at all times. In the two-dimensional channel the gradient flow is limited by the boundaries and is therefore insignificant. In the open sea the gradient flow is evidently preponderant, although it is reasoned that the former should be significant in the immediate vicinity of the coast, where seaward displacement is a necessary condition for removal of fresh water. Doubtless an intermediate state exists in partially enclosed seaways, such as illustrated in Fig. 7 where both gradients and displacement components are considerable.

It may be remarked in the gradient current chart (Fig. 9) that the "fresh-water influence" appears to veer to the right on entering the sea, and moves coastwise until it encounters a second outflow. Then it backs to the left and joins the great ocean stream. From the cross-sections it appears that the coastal current occupies the whole depth along the shore. As this water moves along the coast it encounters a second outflow and is evidently displaced seaward by the fresher outflow. In the

new position the northward course is opposed by the prevailing winds from the north-west and the Japan current, which are evidently greater forces than those involved in the gradient flow. The component of seaward displacement causes the current to back to the left allowing the local fresh water to be dissipated in the ocean.

It is of interest to note that while the upper zone associated with the outflow of a particular river can be identified, the region of influence of that river can be defined. However, when the contributions from several outflows are degraded into a single structure, as illustrated in these last examples, the individuality of the parent river is lost.

The ultimate fate of this upper and intermediate zone have not been fully investigated, but it is remarked that in this and other local examples both of these zones become more saline to seaward, while the salinity of the lower zone remains constant. This implies that deep water is transferred upwards, but no fresh water is transferred downwards, across the boundary, and the mixing force is provided by the wind.

From these and similar examples it is reasoned that fresh water can only be transferred downwards in the sea by external accelerations, such as the wind, or tidal convergences, and in general these are limited to moderate depths. It follows that surface water remains on the surface, and when removed from the influence of coastal streams the salinity of the sea surface increases in the direction of flow because of progressive dilution with underlying sea-water and removal of fresh water by evaporation. The latter process completes the cycle, since all land drainage must be supplied by evaporation.

References

(1) Tully, J. P. (1949) : Oceanography of Alberni Inlet. In *Pub. of Bull. Fis. Res. Bd., Canada.*

(2) Cameron, W. M. : Oceanography of Chatham Sound. (MS. in preparation.)

(3) Tully, J. P. : Oceanography of Georgia Strait, (MS. in preparation.)

(4) ——— (1937) : Oceanography of Nootka Sound. *J. Biol. Bd. Can., 3,* (1).

(5) Jacobson, A. W. (1948) : An Instrument for Recording Continuously the Salinity, Temperature, and Depth of Sea Water. *Trans. Amer. Inst. Elec. Eng., 67.*

(6) Tully, J. P. (1942) : Surface Non-tidal Currents in the Approaches to Juan de Fuca Strait. *Journ. Fish Res. Bd. Can., 5* (4).

(7) Marner, H. A. (1926) : Coastal Currents Along the Pacific Coast of United States. *Pub. No. 121, U.S. Coast and Geodetic Survey.*

(8) Tully, J. P. (1937) : Gradient Currents. *Prog. Rept. Fish. Res. Bd. Can.,* No. 33, Oct.

(9) Ford, W. L. (1947) : Distribution of the Merrimack River Effluent in Ipswick Bay. *Tech. Rept. No. 3 on the Hydrography of the Western Atlantic, Woods Hole Ocean. Inst, Aug.*

(10) Rossby, C. G. (1937) : On the Mutual Adjustment of Pressure and Velocity Distributions in Certain Simple Current Systems. *Journ. Mar. Res., 1,* 1.

(11) Spilhaus, A. F. (1937) : Note on the Flow of Streams in a Rotating System. *Journ. Mar. Res., 1,* 1.

(12) Tully, J. P. (1935) : Kurosio. *Prog. Rept. No. 25, Fish. Res. Bd. Can.*

(13) Tully, J. P. ; Hollister, H. J. ; Fjarlie, R. L. I. ; and Anderson, W. (1949) : A Hydraulic Model of Alberni Harbour. In publication, *Bull. Fish. Res. Bd. Can.*

(14) Tully, J. P. (1937) : A Procedure for Increasing the Accuracy of Surface Current Charts Based on Hydrodynamic Observations. *Journ. Biol. Bd. Can., 3* (2).

Summary of Discussion

Professor Yonge indicated that in his experience a vertical salinity gradient at points of entry of fresh water was not universal, and instanced the Bristol Channel, which seemed to illustrate a pure mixing of a horizontal wall. He admitted, however, that work done on the Tyne and in other localities does agree with Dr. Tully's results. How was the absence of a gradient accounted for in Bristol Channel? It was explained that in shallow water the opposition of strong tidal currents may create these effects.

Dr. Deacon stressed the importance of Tully's work; the biologists ask important and difficult questions which he thought it not yet possible to answer dogmatically. Tully's methods would very soon acquire the strongest importance in marine biology, and would be applied also to oceanic currents from one region to another.

R. E. Owen, Government Printer, Wellington.

How Passamaquoddy Produces Sardines

By A. G. Huntsman

Consulting Director, Fisheries Research Board of Canada
and
Professor of Marine Biology, University of Toronto

On the international border between New Brunswick and Maine lies Passamaquoddy Bay, an arm of the Bay of Fundy, where in tidal ebb and flow the surface of the water falls and rises from twenty to twenty-five feet twice every day. The mouth of this Bay is the focal point of a fishery that for herring alone yields on the Canadian side of the border from thirty to more than a hundred million pounds of fish every year.

Nowhere else in the world (this may be questioned) are there waters to compare with those of Passamaquoddy Bay and vicinity, where such vast quantities of locally grown fish are taken yearly from a small area. How this comes about has been a puzzle, but this seems to have been solved. The solution is that young herring produced elsewhere are carried to the Bay and concentrated in it by currents, and that their food also, although produced elsewhere, is brought to the Bay and concentrated together with them by currents.

Twenty years ago, an international commission selected scientists from Europe and North America to study the matter in connection with the power-fisheries controversy. In two years, they discovered very much concerning the character of the waters, the growth of the microscopic plants upon which as food the animal life is based, the distribution of the small animals that serve as food for the herring, and the life history of the herring. But, they failed to see or to reveal why there is such a Passamaquoddy fishery, which is the basic question. This needs to be revealed if we are to be able to see what is the matter when the fishery goes wrong or to predict each year what quantities and sizes of herring will be available for capture and use, things which the fishing industry desires. In the years since these investigations were carried out new ideas of how the waters work and of how the fish behave have been developed. These, in conjunction with the wealth of facts that scientists and fishermen have made available, seem now to permit us to outline broadly how Passamaquoddy produces sardines. The points made should be tested repeatedly before being fully accepted. Much more work will have to be done before we will be able to understand all the complexities that are involved and to place prediction of the fishery on a sound basis

5 IMPORTANT FACTS

Any explanation of the matter must take account of certain extraordinary facts. (1) No herring spawn in the larger Quoddy region (that is from Cape Spencer just beyond Saint John to Grand Manan Island, including Passamaquoddy Bay), nor are any of their small larvae found in the inner part. Nevertheless there is heavy spawning on the outer side of Grand Manan. (2) During their second season of growth, at the end of which they become sardines, the young herring are concentrated in Passamaquoddy Bay toward the head. In 1951, they were in such tremendous numbers that in the fall nearly ten million pounds of herring that had just become sardines were taken in the weirs from St. Andrews to the head of the Bay and other quantities, together with larger herring, farther out. (3) The great bulk of the small animals on which the herring of the

region feed are not bred in the region, nor even in the Bay of Fundy. They consist of individuals that have been bred and grown in the Gulf of Maine. (4) As a consequence of its heavy tides which make its waters turbulent and turbid, the Bay of Fundy produces but small quantities of the plants necessary as food for the animals. Consequently, this Bay is comparatively barren of fish except to the extent to which these or their food are brought in from the Gulf of Maine. (5) There is a very abrupt change at Cape Spencer in the quantities of fish taken along the New Brunswick shore of the Bay of Fundy. Saint John harbour yields very many fish as far in as the reversing Falls. East of Cape Spencer, the catch is almost nil.

GULF OF MAINE, BAY OF FUNDY, PARTNERSHIP

The broad picture now seen is that the Bay of Fundy and the Gulf of Maine co-operate in production of fish. The Bay provides water that is rich in fertilizer for plant growth through having been churned in tidal action with bottom water and material containing nutrient salts. In the Bay the plants have little chance to grow in this water, since it is too turbid with suspended clay and debris from the bottom for light to penetrate any distance, and since the plants are constantly carried up and down in the turbulent water and fail to remain in the thin surface layer, where alone there is sufficient light for their growth. In the Bay, fresh water from rivers, particularly from the St. John, is mixed thoroughly with a great deal of the sea water, making it relatively light. This light water flows slowly out and spreads somewhat like oil over water at the surface of the Gulf of Maine. As it passes southwestward along the coast of Maine, it is neither turbid nor turbulent when offshore away from tidal action. There it produces steadily a great wealth both of microscopic plants and also of the small animals that feed upon them. This great abundance of food is made available for fish by being carried both inshore to the coast of Maine and back into the Bay of Fundy. This is the explanation of the exceptionally great inshore fisheries that extend from St. John in the Bay of Fundy to Portland at the southwestern end of the broken coast of Maine. Passamaquoddy Bay is only an exceptionally effective part of a region that is highly productive of herring. Also there is more or less interchange of stocks of all sizes of fish with neighboring regions.

The food for fish that is produced in the Gulf of Maine out from the mouth of the Bay of Fundy consists largely of various kinds of small, floating Crustacea, relatives of crabs and lobster. The kinds known to Quoddy fishermen as "shrimp" and "red feed" must get their food from near the surface, but, when out from shore, are deep in the water most of the time. There, they are in a movement that carries them into the Bay of Fundy. To explain this movement: The sea water that is mixed with river water and leaves this Bay has to be replaced. The replacing water flows in at deep levels and also at all depths along the Nova Scotian shore, while the mixed water flows out near the surface and along the New Brunswick shore. The inflow carries the fish food into the Bay. It should be understood that this flow is slight in comparrison with the to and fro tidal currents, which tend to mask it, but it determines where the water and the animals go.

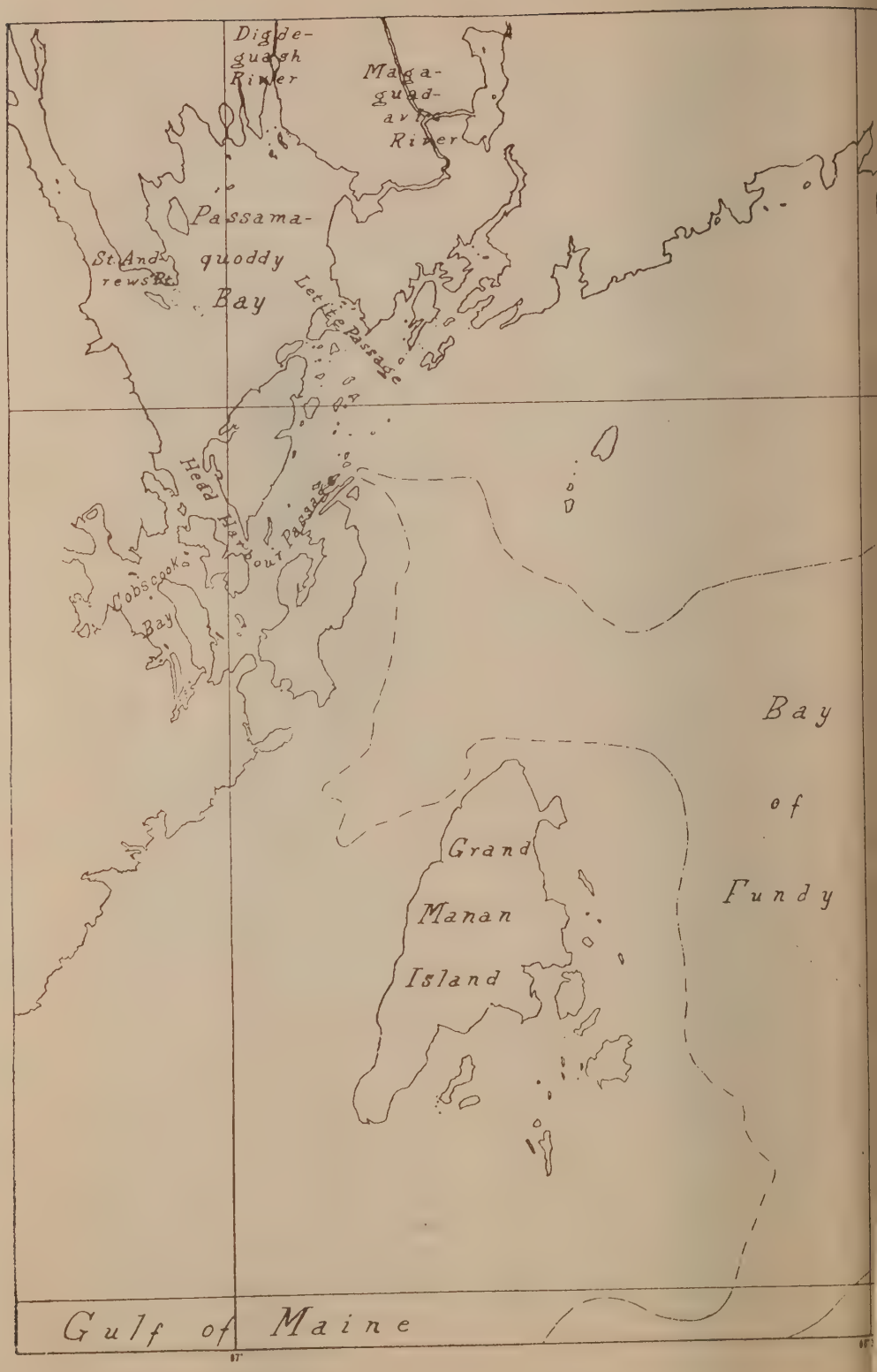
RIVER WATERS IMPORTANT

Most of the river water that enters the Bay of Fundy is discharged into the outer, deeper part and is there mixed with the sea water. An outstandingly large amount of river water, from the St. John, is mixed with twice as much sea water in the Reversing Falls inside St. John har-

bour, the part of the outer Bay that is most distant from the Gulf. The main circulation of fish food from the Gulf is, therefore, in along the Nova Scotian shore to Digby, across to Saint John to reach the Reversing Falls and out along the New Brunswick shore. But, an important short movement is inward near the bottom of the deep water from the mouth of the Bay to the deep mixing that takes place outside Passamaquoddy Bay. These movements of water that carry fish food and fish serve to explain the exceptionally great fishery of the larger Quoddy region from Saint John to Grand Manan. That they do so indicates how dependent that fishery is upon the fall of rain and snow not only locally, but as far away as northern New Brunswick, northern Maine and Quebec, from which the St. John river gets its water. There is evidence of this dependence. After the first Great War, from 1918 to 1923, when there was steady demand by the factories for sardines, the summer head of water in the reservoir of the St. John River from Saint Jonn to Fredericton that determines the outflow through the Reversing Falls alternately fell and rose from year to year with a general decline. The take of sardines followed the same course.

PASSAMAQUODDY MECHANISM COMPLEX

But the above mechanism, does not explain how Passamaquoddy produces sardines. The Passamaquoddy mechanism with its archipelago, bays, estuaries and rivers is much more complex. As shown in the map, the islands of the archipelago partly block the mouths of Passamaquoddy and Cobscook Bays. The rocky and irregular channels between the islands have very turbulent water, as the tidal currents surge through them to raise and lower the level of the inside water very fully. There are very many rivers entering these Bays, each with an estuary in which its water is preliminarily mixed with sea water. For Passamaquoddy Bay proper the most significant are the Digdeguash and Magaguadavic Rivers, which enter at or near its head. This mechanism acts upon the herring in most striking fashion. In summer, but not in winter, the smallest fish prevail in Passamaquoddy Bay toward its head, the largest fish are outside Grand Manan Island, and the intermediate sizes are between these two places. To understand how this segregation in sizes is brought about, it must be appreciated that herring on the whole go where they are carried, since they do not react in their swimming to the bottom or the shore except when very near them. In summer, herring swim actively up in the water but at some distance from the surface except after dark. This distance depends upon the size of the fish, the smallest fish being nearest the surface. The circulation of the water, which carries the fish from place to place, varies considerably with the depth when the water has layers of different density from mixing of fresh water with the salt water. While all sizes of herring may be together in the centre of the region (just outside the entrances to Passamaquoddy Bay), when they are all relatively inactive and deep in the water in winter, they will be separated according to size by the circulation when they rise toward the surface in spring and occupy different levels. The complex circulation is such as to carry those nearer the surface into Passamaquoddy Bay and to concentrate them near its head, and to carry those deeper in the water oceanward and to concentrate them outside Grand Manan. This action of the circulation can be readily observed for the large white jellyfish that is to be seen on calm days in midsummer in great banks close to the surface of Passamaquoddy Bay. Although mixed water


Digde-
guash
River
Maga-
guad-
avic
River
Passama-
quoddy
Bay
St. And-
rews Pt.
Letite Passage
Head
Harbour Passage
Cobscook
Bay
Bay
of
Fundy
Grand
Manan
Island
Gulf of Maine

works out of this Bay, the jellyfish are not carried away, being rare in the passages leading out. The explanation of this is that light water from the estuaries of the Digdeguash and Magaguadavic Rivers forms the surface layer of the Bay and this is rather steadily moving toward the west or inner shore from St. Andrews to the head of the Bay to be there mixed with the deep water. The mixed water moves outward and toward the mouth of the Bay at an intermediate level and thus carries away those fish or other animals that are deep enough in the water to be in it.

The separation of the sizes of herring is of considerable importance in the production of sardines. Because of it the larger fish are not able to take food away from the small ones that are to become sardines. The Passamaquoddy mechanism protects the small herring in more ways than this. It is quite effective in separating the small herring from their enemies. Some of the enemies do get into Passamaquoddy Bay in late summer when the mechanism is apt not to work too well. Dogfish circle around the schools of small herring and pick up the stragglers. Mackerel dash into the schools and break them up. Silver hake and squid drive the schools into shallow water and feed on them at leisure. With enemies present not only do their numbers diminish, but also they are kept from feeding. For the most part however, pollock and cod are kept at the entrances to the Bay by the mechanism, and dogfish, silver hake, squid and mackerel are kept out of the region, presumably in the same way that the large herring are so kept in summer

PRODUCTION OF LARVAL HERRING

With its lack of floating microscopic plants, the Bay of Fundy is unsuitable for the growth and survival of the larval herring. This Bay and the Gulf of Maine co-operate in effective production and growth of larval herring. The large Quoddy herring that are concentrated outside Grand Manan spawn in late summer and produce immense numbers of larvae. These rise from the bottom and are carried in the outflow from the Bay along the Maine coast, where they have a dependable and rich supply of food as has already been described. Every year, therefore, there is a large quantity of rapidly growing herring larvae in the Gulf out from the Bay of Fundy. There is no nearer source of these to populate Passamaquoddy Bay. The Bay of Fundy and the Gulf form a single circulating system, as is shown by the hydrographic facts and by the movements of drift bottles, as well as by the movements of the floating animals, as has been described. Therefore, Passamaquoddy Bay can draw upon whatever stock of herring are produced in the Bay of Fundy and in the Gulf of Maine or that reach these waters from elsewhere. The spawning at Grand Manan seems likely to be the main source.

CIRCULATION THROUGH LETITE

The larger herring larvae are difficult to capture so that their movements cannot well be followed. When they reach in spring the stage called "eye-balls" by the fishermen, in which they are still transparent except for black pigment just outside the retina of each eye, they collect in schools and keep near the surface. Then it is that they appear in Passamaquoddy Bay. It was discovered in 1951 that both surface and deep water from the Bay of Fundy work into Passamaquoddy Bay through Letite Passage, while the mixed water works out through the western or Head Harbour Passage. Doubtless, therefore, the "eyeballs" enter the Bay of Fundy from the Gulf of Maine along the Nova Scotian shore, make the circuit of the Bay and reach Passamaquoddy Bay through

Letite Passage. Drift bottles show that surface water takes this course, one bottle even reaching Bocabec Bay at the head of Passamaquoddy Bay. In the latter Bay, the "eyeballs" are concentrated toward the head and retained. They soon transform into britt, becoming similar to larger herring.

If they are to survive, food must be provided for all the briti that may be concentrated in Passamaquoddy Bay. There is some local production of small kinds of "red feed", and in fact such production is large for the Bay of Fundy, but this is far from being enough. The course by which the "eyeballs" are brought and concentrated here is one by which small organisms including small kinds of "red feed", which similarly keep near the surface, will also be brought and concentrated here. They come from the Bay of Fundy and from the Gulf of Maine, and serve both "eyeballs" and britt for food. There is also another source of food for the britt. Larger kinds of "red feed" and "shrimp" that keep deep in the water are brought, as has been mentioned, to the deep water outside Passamaquoddy Bay. The movement of the water in through Letite brings them in as it does the surface forms. In the turbulent water of the Passage, they are to be found at the surface mixed with the surface forms. Inside the Passage the two kinds separate, keeping near the bottom and near the surface respectively. The britt would not eat the deep forms were they not brought up in the mixing along the shores of the Bay. The mixing of deep water with surface water is particularly strong on the west side of the Bay from St. Andrews toward the head. Britt, surface forms and deep forms are concentrated together there. The britt are thus brought into close relation with their food for easy feeding. There were so many britt in the summer of 1951 and they were so well provided with food that, as observed at the beginning of August, the surface of the Bay was thickly peppered with their excreta, about a twelfth of an inch in diameter, which were sometimes cast upon the beach in masses.

ACTION OF HEAD HARBOUR PASSAGE

The larger sardines, which become two years old late in the summer, are found mainly in the channels of the archipelago between Passamaquoddy Bay and the Bay of Fundy. They have the best feeding. The fattest herring of the whole region are taken in Head Harbour Passage and in the shallow Harbour de Loutre and Cobscook Bay that receive their water through that Passage. The "shrimp" are sometimes so abundant there as to be cast up on the beach in windrows. The "red feed" is sometimes so abundant that herring held in weirs get all they can eat, and remain feedy and unsalable for long periods. The "shrimp" and "red feed" consist of deep-water forms brought from the Gulf of Maine in a deep channel that ends just outside the mouth of the Passage. In the Passage, which is long, deep and irregular, the mixed water issuing from Passamaquoddy Bay is again mixed in strong tidal boils and whirlpools with salter and heavier water that enters from outside. The volume of the resultant mixed water is so great and its outward movement is so slow that the outflow is quite deep. The outside water that enters is deeper still and brings in the "red feed" and "shrimp" in large quantity. In the Passage, these can no longer keep to the depths, but are carried up and down in the boils and whirlpools and so become available not only to the herring and to the pollock, which live near the surface, but also to large flocks of gulls, terns and phalaropes, which feed at the surface.

INFLUENCE OF HEAVY RAINFALL

It has been found that heavy rainfall over the country that drains into Passamaquoddy Bay increases the amount of fish food that enters Head Harbour Passage from outside. While the discharges of the St. Croix and Magaguadavic Rivers are controlled for power purposes, the Digdeguash River at the head of the Bay goes into flood with rainfall. Several inches of rain fell over its whole drainage system in one night on two occasions, in September of 1933 and in August of 1951. Each time there was a very heavy flood. The fish food in the Passage was sampled at intervals afterwards and in both cases there was a sudden marked increase in its amount in about eleven days, the time necessary for the flood of fresh water to work outward through the Digdeguash estuary, the Bay and the Passage.

Study will probably reveal that sardines are produced in somewhat similar fashion all along the Atlantic coast where herring are found. But it is clear that the numbers produced elsewhere are not nearly so great as in Passamaquoddy.

HISTORY OF SARDINE FISHING

If prediction of the fishery is to be successful, it is necessary to follow the course of the events that determine it. Knowledge of the past permits us to foresee the future. The history of the Quoddy fishery is exceptionally interesting. When large "net" herring for salting were alone in demand, the fishery was outside Grand Manan where the large herring were congregated and where as many as 120 vessels operated their nets at one time. When smoking of the smaller "stringers" developed, the fishery was extended inwards to Campobello and Deer Islands. When canning of the "sardines" began, it was extended farther in to the head of Passamaquoddy Bay and to Oak Bay up the St. Croix estuary. At each step in using smaller fish, there was an outcry that the fishery would be ruined. In the early 1890's, when heavy removal of "babies" had been going on for more than a decade, the matter was investigated by a scientist from the U. S. Bureau of Fisheries. Since it was incontrovertible that there was no lack of the young, maintenance of the stock could not be said to be in danger. With strong demand and intense fishing for those little more than a year old, the total poundage of herring taken annually has continued for over seventy years at a general level twice as high as before sardines began to be canned. The facts indicate that development of the sardine industry (1) at once did away with the very fat Quoddy river herring which were being taken near the first factories at Eastport, (2) greatly decreased the numbers of large spawning herring, thus eliminating the winter fishery for the spent fish, (3) at first increased and then decreased somewhat the numbers of the "stringers" or smoking herring, and (4) increased the numbers of sardines.

TO SUM UP

The Bay of Fundy and the Gulf of Maine co-operate in producing an abundant and dependable supply of fish food in the Gulf out from the mouth of the Bay. The Bay furnishes rich water for plant growth and the Gulf grows the plants and the small animals that feed upon them. A circulation set up by tidal mixing of sea water with the river water discharged into the outer part of the Bay, particularly from the large St. John River, transports fish food and fish from the Gulf into the Bay. This gives important shore fisheries from Saint John to Grand Manan. The Bay and the Gulf co-operate in producing yearly large numbers of herring larvae. The Bay has extensive spawning of herring just outside Grand Manan in late summer. The

Gulf provides an abundant and dependable supply of food for the larvae when they rise from the bottom and are carried southwestward in the outflow from the Bay. In the spring, the common circulation of the Gulf and Bay takes the well-grown larvae from the Gulf into the Bay and thence into Passamaquoddy Bay through Letite Passage. The young herring, thus brought in, are concentrated and held toward the head of Passamaquoddy Bay together with an ample supply of food, which is similarly brought in from outer waters. There it is that young herring in very large numbers become sardines. The larger sardines that are around two years old are mainly congregated in the channels at the entrances to Passamaquoddy Bay. There they are provided with a very rich supply of deep water forms. The latter are brought from the Gulf in the circulation set up by the mixing of fresh and salt water in those channels, and farther out in the Bay of Fundy. The complex circulation that constitutes the Passamaquoddy mechanism, not only concentrates in Passamaquoddy Bay the small herring that are to become sardines, but also keeps away from them both the larger herring that compete with them for food and the fishes that eat them, such as cod, pollock, mackerel, silver hake and squid.

My work on this matter has been under the Fisheries Research Board of Canada. Many persons have made contributions to the picture that has been presented, but I alone am responsible for any defects it may have. It is a pleasure to acknowledge that I have been able to consult the following persons for critical comments: Dr. H. B. Bigelow of Harvard University, Prof. Trygve Braarud of Oslo University, Dr. J. R. Dymond of the University of Toronto, Mr. Michael Graham of the Lowestoft Fisheries Laboratory in England, Dr. H. B. Hachey of the Atlantic Oceanographic Group, Prof. Martin W. Johnson of the University of California, Dr. A. H. Leim of the Atlantic Biological Station, Dr. A. M. A. McLean of Connors Bros. Limited, Dr. A. C. Redfield of the Woods Hole Oceanographic Institution, Dr. W. E. Ricker, Editor of the Fisheries Research Board of Canada, Mr. O. A. Rigby, District Protection Officer of the Department of Fisheries, Mr. J. C. Stevenson of the Pacific Biological Station and Dr. E. E. Watson of Queen's University.

(Reprinted from Fundy Fisherman, November 26.)

Reprinted from ANALYTICAL CHEMISTRY,
Vol. 25, Page 187, January 1953
Copyright 1953 by the American Chemical Society and
reprinted by permission of the copyright owner

Semimicrodetermination of Dissolved Oxygen

E. L. HARPER, *Pacific Biological Station, Fisheries Research Board of Canada, Nanaimo, B. C.*

THE Winkler method (*1*, *3*) has long been recognized as one of the simplest and most accurate for the determination of dissolved oxygen. The following semimicro modification has been found satisfactory for oceanographers where the volume of sample available for analysis is small, as from the Spilhaus sea sampler (*4*), and for limnologists who find a light, portable kit convenient.

REAGENTS

The reagents and their concentrations are given by Scott (*3*) or in (*1*). If the sample contains much organic matter the iodide concentration may be increased as recommended by Pomeroy (*2*).

APPARATUS

Reagent Bottles. The reagents are carried in small dropping bottles, capacity about 30 ml., or in bottles fitted with fine-tipped eye droppers through rubber stoppers. The volume of the average drop delivered by each bottle or eye dropper should be predetermined and the number of drops constituting the necessary volume (0.1 ml.) of each reagent should be noted.

Sample Bottles. Borosilicate glass Shell vials, 25 by 75 mm. (capacity about 37 ml.), are used. They should be chosen so that their diameters are constant within 0.2 mm.

Stoppers. Each vial is provided with a tightly fitting one-hole rubber stopper (No. 5) through which a glass tube, 6 mm. in outside diameter, is fitted flush with the bottom and projecting 2 or 3 mm. above the top. The upper end is flared as shown in Figure 1.

Measuring Device. A two-hole rubber stopper is fitted with two glass tubes (4 mm. in diameter) vulcanized in position. One tube is long enough to reach the bottom of the vial, and the other is 1 cm. shorter. When the vial is inverted, the solution drains to the level of the shorter tube leaving the aliquant in the vial. The volume of the aliquant is dependent on the length of the shorter tube, which is constant, and the diameter of the vial. The maximum variation in diameter, 0.2 mm., may result in a 0.9% volume error.

Each measuring device is standardized by weighing the volume of distilled water remaining in the vial. Two measuring devices were tested. In both cases the results of eight weighings varied by ±0.05 gram in 21 grams, indicating a 0.24% deviation from the mean.

Buret. A 2-ml. pipet, graduated to 0.05 ml., is made into an automatic buret by fitting to it a three-way stopcock, and connecting it to a solution bottle. The titer is usually less than 2 ml. and can be estimated to 0.005 ml. which provides sufficient accuracy while the titer exceeds 0.500 ml.

PROCEDURE

The clean sampling vial is rinsed three times with about 5 ml.

of the sample. The sample is then let into the bottom of the vial through a small bore ($^1/_8$-inch) rubber tube which is slowly withdrawn as the vial is filled, so that the end remains below the surface of the sample.

Three drops (0.1 ml.) of reagent 1, manganous sulfate solution, are dropped on the surface of the sample from the reagent bottle, and sink rapidly to the bottom.

The vial is closed with the one-hole stopper (Figure 1) so that no air is entrapped. Air bubbles may be eliminated by pressing the stopper down, forcing some of the sample out the tube.

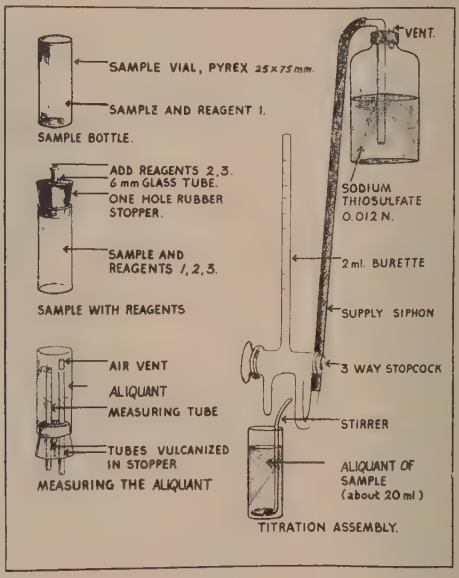


Figure 1. Apparatus

Three drops (0.1 ml.) of reagent 2, hydroxide-iodide solution, are dropped into the flared tube through the stopper. Within 30 seconds the reagent sinks to the bottom, forming a brownish precipitate. With one finger over the flared tube the vial is inverted several times to mix the contents. The solution is allowed to stand for about 10 minutes or until about a third of the solution is clear.

Three drops (0.1 ml.) of reagent 3, concentrated sulfuric acid, are then added through the flared tube. This should be done slowly to allow the drops to sink into the solution with no substantial amount of the reagent being lost in the overflow. When the reagent has drained completely into the vial it is reagitated and allowed to stand until the precipitate has completely dissolved.

The one-hole rubber stopper is then replaced by the measuring device with the shorter tube in the center of the vial to ensure accurate measurement. The vial is inverted, and the solution above the short tube allowed to drain to waste.

The sample bottle is then turned upright, the measuring device is removed, and the remaining aliquant is titrated—in the sample bottle, using a glass stirring loop—with sodium thiosulfate, from the 2-ml. buret to a starch end point.

CALCULATION

$$\text{Milligrams of oxygen per liter} = 8000 \times \frac{\text{titer} \times \text{normality of } Na_2S_2O_3}{\text{volume of sample titrated}}$$

where the volume of the sample titrated is equal to

$$\text{Volume of aliquant} - \left(\frac{\text{volume of aliquant}}{\text{volume of sample}} \times \text{volume of reagents 1 and 2}\right)$$

Only the volumes of reagents 1 and 2 need be considered since reagent 3 displaces only oxygen-free sample.

NOTES ON METHOD

The precision of each step of the proposed semimicroprocedure was compared with the standard macroprocedure, and the optimum conditions were determined. In each trial, 3 to 5 samples were drawn by siphon from a pail of freshly obtained seawater into biochemical oxygen demand bottles (approximately 300 ml.) and treated in the standard manner (*1*). At the same time, a similar number of semimicro samples were taken and treated according to the experimental procedure. One measuring device was used with the series of sample vials. A comparison of results obtained in this manner is shown in Table I.

It was found that if reagents 1 and 2 were added directly to the surface of the sample before stoppering the vial, the results varied more than 1%. The apparent concentration of dissolved oxygen may be too high owing to the reaction of reagents at the surface with the atmosphere; or too low owing to loss of manganic precipitates by displacement when the stopper is

Table I. Comparison of Concentration of Dissolved Oxygen Observed in Sea Water by Standard Winkler Procedure and Semimicroprocedure

	Macro (116 Ml.)		Micro (21 Ml.)		
	Titer	Mg. O_2/liter	Titer	Mg. O_2/liter	
Trial 1	11.08	9.06	2.00	9.00	
	11.06	9.00	2.00	9.00	
	11.10	9.07	2.01	9.05	
	11.05	9.04	2.01	9.05	
	Averages, Mg. O_2/liter				Difference
Trial 1	9.04 ± 0.04		9.02 ± 0.02		0.02
Trial 2	8.96 ± 0.05		8.92 ± 0.04		0.04
Trial 3	8.87 ± 0.05		8.84 ± 0.03		0.03

inserted. Both reagents 1 and 2 may be added through the hole after stoppering, if sufficient time is allowed for complete drainage of the first reagent before adding the second.

For precise work the measuring stopper should be identified only with the vial in which it is standardized, in which case the volume error does not exceed 0.24%.

The usual precautions in using the Winkler method must be observed (*1*). The sodium thiosulfate should be standardized under the same conditions used in the analyses.

LITERATURE CITED

(1) American Public Health Association, "Standard Methods for the Examination of Water and Sewage," pp. 127–9, New York, American Public Health Association, 1946.
(2) Pomeroy, R., and Kirschman, H. D., IND. ENG. CHEM., ANAL. ED., **17**, 715 (1945).
(3) Scott, J., "Standard Methods of Chemical Analysis," pp. 1436–7, New York, D. Van Nostrand Co., 1925.
(4) Spilhaus, A. F., "Bathythermograph and Sea Sampler," Woods Hole Oceanographic Institution, 1941.

RECEIVED for review November 13, 1951. Accepted September 8, 1952.

PRINTED IN U. S. A.

Reprinted from JOURNAL OF MAMMALOGY
Vol. 34, No. 1, February 1953, pp. 98–104
Printed in U.S.A.

TWO RECORDS OF *BERARDIUS BAIRDI* FROM THE COAST OF BRITISH COLUMBIA

BY GORDON C. PIKE

During 1950 and 1951 two Baird's beaked whales, *Berardius bairdi* Stejneger, were harpooned off the northwest coast of Vancouver Island and subsequently processed at the shore whaling station operated by British Columbia Packers Company Limited at Coal Harbour, British Columbia. The first, a 33-foot adult male, was taken on July 5, 1950 about 10 miles off Kains Island, Quatsino Sound. The second, a 29-foot immature female, was taken on August 9, 1951, 20 miles ESE of Cape St. James. The two specimens are the first records of this species from the coast of British Columbia.

Berardius bairdi, one of the little known members of the whale family Ziphiidae, has previously been recorded from California, Washington, the Bering Sea, and Japan. Records of the species from the eastern North Pacific are rare, but in waters adjacent to Japan over 300 were taken commercially under the name of "Tsushi-kujira" in 1949 and 1950 (Japan Whaling Association, 1951).

In general, the external form of the two British Columbia specimens corresponds to previous descriptions of the species as compiled by True (1910). A narrow elongated snout extends forward from a well-defined forehead. The body tapers from its greatest girth between the flippers and the dorsal fin to a slender tail region terminated by broad flukes (Plate I, 1 and 2). The flippers are small (Plate I, 4). The dorsal fin is small and is situated well behind the middle of the body (Plate I, 3). The lower jaw, armed with only two inconspicuous pairs of teeth, extends slightly beyond the tip of the toothless upper jaw. The V-shaped grooves beneath the chin, characteristic of the Ziphiidae, are deep and well defined (Plate I, 1). In the male specimen the forehead rises abruptly almost at right angles to the beak from a distinct transverse groove (Plate I, 5). In the female the bulge on the forehead is less prominent and no transverse groove is apparent.

In these specimens the body is black on the head, back, flukes and flippers. The undersurface is of a slightly lighter shade, with white and gray markings. The male has a conspicuous diamond-shaped white patch at the umbilicus and some white around the genital opening. The female is lighter in colour and the skin was covered by abrasions caused while the whale was being towed into the station. Numerous white scratch marks appear on the back and flanks of both

PLATE I

(1) Ventral view of 33-foot male *Berardius bairdi*. (2) Dorsal view of 29-foot female. (3) Dorsal fin of 29-foot female. (4) Left flipper of 29-foot female. (5) Head view of 33-foot male.

specimens (Plate 1, 5). These scratch marks, when found on males of other Ziphiidae and Delphinidae, have been attributed to the teeth of rival males. This

explanation seems unlikely to be applicable to this species whose teeth are either buried in the gum or are blunt and protrude only slightly. A more plausible explanation for all species is that the scratches are caused by the sharp "beaks" of the squid on which they feed. Similar scratches are found on the heads of sperm whales.

The external features of these specimens differ only in minor particulars from the descriptions compiled by True (1910). The flippers are not pointed, but are similar to those of the sperm whale (Plate I, 3). Unlike other Ziphiidae, the posterior emargination of the dorsal fin is not concave (Plate I, 4). The female has a slightly concave hind margin to the flukes and the male has a median notch nine inches deep in the hind margin of the flukes. A characteristic of the Ziphiidae is that the hind margin of the flukes is slightly convex with no median notch. Although the notch in the male appeared to be natural, it may well have been the result of an early injury.

The V-shaped throat grooves in the male specimen are each 26 inches in length; they converge and almost meet at a point 17 inches from the tip of the lower jaw (Plate I, 1). A short but deep median groove six inches long commences 22 inches from the tip of the lower jaw. The throat grooves in the female are each 24 inches long, commencing 16 inches from the tip of the jaw. The two grooves are two inches apart at the posterior extremity; no median groove separates them as in the male.

Measurements of body proportions are presented in Table 1 in feet and inches and as percentages of the total length from the tip of the snout to the hind margin of the flukes. The series of measurements is based upon that used by the British Discovery Committee for describing the larger commercial species of whales (Mackintosh and Wheeler, 1929). Comparison of measurements for the two specimens shows clearly that the head is relatively larger, the flipper smaller, and the dorsal fin slightly larger for the female than for the male. The breadth of the body behind the flippers appears to be greater in the female.

Table 2 compares selected body measurements of the two British Columbia specimens with those from two specimens of *Berardius bairdi* from St. George Island and one specimen of *B. arnuxi* from New Zealand, as percentages of the total length (True, 1910). The values correspond closely for all the North Pacific specimens. The discrepancy in the value of "tip of mandible to corner of mouth" for the female specimen is probably a result of the poorly defined point, "corner of mouth". The comparison bears out True's observation that the flukes are wider and the flippers longer in *Berardius bairdi* than in *B. arnuxi*.

A character used by True and others to distinguish *Berardius bairdi* from *B. arnuxi* is the relative size of the head, which is said to approximate one–eighth of the total length in the former species and one–seventh in the latter species. Table 3 shows the extreme variability of this character and suggests its unreliability as a diagnostic feature. Relative skull lengths in these specimens vary from less than one–seventh to more than one–eighth of the total length.

Measurements of the skulls, which are being retained at the Pacific Biological Station, Nanaimo, British Columbia, are presented in Table 5 in millimetres and

: percentages of the postorbital width. Proportions are not given as percentages the total length because a small part of the premaxillary tips were broken off uring the process of cleaning the male specimen. These tips are extremely agile and are probably damaged to some extent in most specimens. The comarison shows the female skull to be more robust than the male skull.

ABLE 1.—*Measurements and body proportions of Berardius bairdi from British Columbia*

	MALE			FEMALE		
	FT.	IN.	% OF TOTAL LENGTH	FT.	IN.	% OF TOTAL LENGTH
otal length from tip of snout to hind margin of flukes	33	3	100.0	29	3	100.0
rojection of lower jaw beyond tip of snout	—	4	1.0	—	1	0.3
ip of snout to blow-hole	3	8	11.0	3	7	12.2
ip of snout to angle of gape	2	1	6.3	2	2	7.4
ip of snout to centre of eye	3	6	10.5	3	7	12.2
ip of snout to tip of flipper	10	5	31.3	9	3	31.6
ind margin of flukes to posterior emargination of dorsal fin	10	5	31.3	9	6	32.5
idth of flukes at insertion	2	9	8.3	2	3	7.7
ind margin of flukes to anus	10	2	30.6	9	0	30.8
ind margin of flukes to umbilicus	19	6	58.6	17	2	58.7
entre of reproduction aperture to centre of anus	2	6	7.5	—	—	—
eight of dorsal fin	—	9	2.3	—	9	2.6
ength of base of dorsal fin	2	3	6.8	2	2	7.4
xilla to tip of flipper	2	9	8.3	2	6	8.5
ip to anterior end of lower border of flipper	4	4	13.0	3	6	12.0
ength along curve of lower border to tip of flipper	4	5	13.3	3	10	13.1
reatest width of flipper	1	5	4.3	1	4	4.5
ength of severed head from condyle to tip	4	9	14.3	4	7	15.7
ength of flipper from head of humerus to tip	4	2	12.5	3	6	12.0
epth of body at dorsal fin	6	3	18.8	4	4	14.8
otal spread of flukes	9	6	28.6	—	—	—
idth across blow-hole	—	6	1.5	—	7	2.0
ip of snout to forehead groove	2	5	7.3	2	0	6.8
readth of body at flippers (including flippers)	3	8	11.0	—	—	—
readth of body at blow-hole	3	0	9.0	3	2	10.8
lubber thickness on flank in line with dorsal fin	—	3.5	1.1	—	4	1.3

The two pairs of teeth are roughly triangular in side view, with rugose bases ecurely attached by closed roots in their alveoli. The teeth protrude slightly bove the gum in the male but are completely buried in the female. The apices f the larger anterior pairs are considerably abraded in the male but are sharply cute in the female. A shallow, median, longitudinal groove in the base of each

tooth from the female suggest that the sides had recently drawn together to form closed roots. Measurements of the teeth and their positions on the mandibles are presented in Table 4.

Stomach contents of the male consisted of a few hard and soft parts of small squid and a single skate egg case. The food, about two gallons in all, was accompanied by numerous nematodes. Stomach contents of the female consisted of about two gallons of small rockfish and squid remains accompanied by a few nematodes. The only external parasites were a few caprellid amphipods similar to the species of *Paracyamus* commonly occurring on humpback whales. These were found only on the male and were concentrated chiefly in the region of the teeth. The skin of the female was invested by a film of diatoms consisting of ex-

TABLE 2.—*Body proportions of Berardius bairdi and Berardius arnuxi*

	BAIRDI				ARNUXI
	BRITISH COLUMBIA		U.S.N.M. 49726	U.S.N.M. 49727	NEW ZEALAND (HECTOR)
	ADULT ♂	YOUNG ♀	ADULT ♀	YOUNG ♂	MALE
Total length	ft. in. 33 3	ft. in. 29 3	ft. in. 40 2	ft. in. 25 5	ft. in. 27 6
	%	%	%	%	%
Distance from tip of snout to blow-hole	11.0	12.2	10.8	11.5	12.8
Distance from tip of mandible to corner of mouth	6.3	7.4	6.9	6.3	6.1
Length of pectoral fin along outer edge	13.0	12.0	12.4	13.4	9.4
Breadth of flukes from tip to tip	28.6	—	25.3	24.6	19.1
Height of dorsal fin	2.3	2.6	2.5	2.4	3.0
Distance from anus to "end of body"	30.6	30.8	29.0	29.8	(34.0)

TABLE 3.—*Head lengths of Berardius bairdi*

LOCALITY	SEX	TOTAL LENGTH (FT.	IN.)	SKULL LENGTH (MM.)	SKULL LENGTH: TOTAL LENGTH (PER CENT)
British Columbia	Female	29	3	1343	15.1
Ocean City, Wash.	Female	34	5	1438	13.7
St. George Island	Female	40	2	1524	12.4
St. George Island	Male	25	5	1062(?)	13.7
British Columbia	Male	33	3	1440	14.2
Centerville, Calif.	Male(?)	41	0	1532	12.3

TABLE 4.—*Teeth of British Columbia specimens of Berardius bairdi*

	DISTANCE BETWEEN APICES OF 1ST AND 2ND TEETH IN MM.	LARGE TOOTH		SMALL TOOTH	
		GREATEST HEIGHT MM.	GREATEST BREADTH MM.	GREATEST HEIGHT MM.	GREATEST BREADTH MM.
33-ft. male	151	89	103	60	37
29-ft. female	140	93	72	55	33

sive brown areas of *Cocconeis* and small dispersed centres of *Navicula*. Two sh marks of the Pacific lamprey, *Entosphenus tridentatus*, were found on the nale. Neither diatoms nor lamprey marks were noted on the male.

Examination of the degree of fusion of the epiphyses of the thoracic vertebrae h their centra showed the male to be physically mature and the female to be ysically immature. The female was also sexually immature. Its ovaries, weigh-

TABLE 5.—*Skull measurements of Berardius bairdi from British Columbia*

	LENGTH IN MM.		PER CENT OF POSTORBITAL WIDTH	
	33 FT. ♂	29 FT. ♀	33 FT. ♂	29 FT. ♀
al (condylobasal) length	1,440	1,343	187.0	203.8
ght from vertex to inferior border of pterygoids	569	525	73.9	79.7
adth across middle of orbits	693	657	90.0	99.7
adth across postorbital processes	*770*	*659*	*100.0*	*100.0*
adth across zygomatic processes	732	660	95.0	100.2
gth of rostrum	908	870	117.0	132.0
adth of rostrum at base	447	397	58.1	60.2
adth of rostrum at middle	208	194	27.0	29.4
gth of premaxilla	1,220	1,192	158.4	180.9
adth of premaxilla at middle	132	138	17.1	20.9
atest breadth of premaxillae in front of nares	238	239	30.9	36.3
atest breadth of premaxillae behind nares	204	203	26.5	30.8
tance from anterior end of premaxillae to posterior end of pterygoids (median)	1,146	865	148.8	131.3
tance from anterior end of premaxillae to anterior end of vomer	263(?)	280	34.2	42.5
gth of portion of vomer visible on palate	438	354	56.9	53.7
gth of nasals (greatest, median, straight)	120	110	15.6	16.7
adth of nasals (greatest)	110	125	14.3	19.0
adth of anterior nares	98	94	12.7	14.3
adth of foramen magnum	86	72	11.2	10.9
adth across occipital condyles	246	216	31.9	32.8
adth of each condyle	115	100	14.9	15.2
ght of each condyle	180	173	23.4	26.3
gth of mandible	1,334	1,190	173.2	180.6
ght of coronoid	241	212	31.3	32.2
tance from tip of jaw to centre of 1st tooth	38	30	4.9	4.6
tance from tip of jaw to centre of 2nd tooth	189	170	24.5	25.8
st depth of mandible behind 1st tooth	110	93	14.3	14.1
tral face to apex of 1st tooth crown	138	98	17.9	14.9

less than two ounces each, contained no corpora lutea or maturing follicles. e testes of the male were not found but it is presumed that the animal was ually adult.

Some information concerning the habits of this species is provided by members he whaling crews responsible for the capture of the two specimens. The school n which the male was taken consisted of about 20 individuals, many of them ger than the one captured. Upon surfacing, all members of the school except

one, a large animal which appeared to be the leader, seemed to rush together. The leader remained about 100 yards from the rest of the school and dived independently. From a distance, and before being approached, the whales were seen to raise their flukes in the air like sperms when diving. The blows numbered about fifteen in quick succession. The female was taken from a school of about 20 individuals and two other schools about the same size were in the vicinity at the time. No leaders were observed but numerous calves were seen. Attesting to the agility and deep-diving propensities of this species is the fact that the male, when struck by the harpoon, dived straight down at an amazing speed, taking with it 500 fathoms of line.

The limited number of records of *Berardius bairdi* reflects in part a lack of attention paid the beaked whales. British Columbia whalers report that schools of this species are commonly seen in July and August. Barabash-Nikiforov (1938) reports that *Berardius* often forms large schools in the vicinity of the Commander Islands. Recent records of the species include a 34-foot adult female washed ashore at Ocean City, Washington in July, 1950 (Slipp and Wilke, 1953), and a 34-foot male taken from a school of about twenty at the Eureka whaling station in California in May, 1951. Whales from this coast reported as "Bottlenose" are probably *Berardius*, as the true "bottlenose", *Hyperoodon*, has never been certainly recorded from the North Pacific (Slipp and Wilke, 1952). Prewar whaling statistics for the west coast of North America show the catch of eight "bottlenosed whales" at Bay City, Washington, and seven from the coast of British Columbia (Kellogg, 1931; Scheffer and Slipp, 1948).

LITERATURE CITED

Barabash-Nikiforov, I. 1938. Mammals of the Commander Islands and the surrounding sea. Jour. Mamm., 19: 423–429.

Japan Whaling Association. 1951. Some materials showing the status of whaling of Japan. Fisheries Agency of the Japanese Govt., Tokyo, Japan. 31 p.

Kellogg, R. 1931. Whaling statistics for the Pacific Coast of North America. Jour. Mamm., 12: 73–77.

Mackintosh, N. R. and J. F. G. Wheeler. 1929. Southern blue and fin whales. Disc. Repts., 1: 257–540

Scheffer, V. B. and J. W. Slipp. 1948. The whales and dolphins of Washington State with a key to the cetaceans of the west coast of North America. Amer. Mid. Nat., 39: 257–337.

Scheffer, V. B. 1949. Notes on three beaked whales from the Aleutian Islands. Pac. Sci., 3: 353.

Slipp, J. W. and F. Wilke. 1953. The ziphiid whale *Berardius* on the Washington coast. Jour. Mamm., (this issue).

True, F. W. 1910. Account of the beaked whales of the family Ziphiidae in the collection of the United States National Museum, with remarks on some specimens in other American museums. Bul. U. S. Mus. Nat. Hist., 73: 1–89.

Pacific Biological Station, Nanaimo, British Columbia. Received February 11, 1952.

Reprinted from THE JOURNAL OF THE AMERICAN OIL CHEMISTS' SOCIETY, December 1951 Issue, Vol. XXVIII, No. 12, pp. 512-513]

The Hydrogen Value — Refractivity Relationship of Unsaturated Fatty Acids of Natural Origin

F. A. VANDENHEUVEL[1] and E. H. FARMER[2]

IN a previous paper (2) the authors have shown that a relationship exists between the refractive indices and the unsaturation value (iodine or hydrogenation value) of unsaturated fatty esters derived from cod liver oil, haddock liver oil, and sardine oil. When the refractive indices were plotted against the hydrogenation values, a straight line D_1H (Fig. 1) was obtained; this line remained unbroken until a point H, corresponding with the C_{22} hexaene acid, was reached, after which it continued in a new direction. The curve was directly applicable to pure individual esters as well as to unresolved fractions unless the latter contained components belonging to the different branches of the curve. It was stated that "whatever the precise significance of the hydrogen value/refractivity curve, the latter appears to offer direct and trustworthy empirical indication as to whether a product is an original component or only a secondary one."

Since the publication of this paper, some pure methyl esters of unsaturated fatty acids have been derived from natural materials of widely different origins. The experimental conditions under which they were prepared offer a good guarantee as to the original structure being conserved. Their constitution is well established, and they cover a wide range of unsaturation.

It is the purpose of this paper to show that the refractive indices published for these products as well as their unsaturation values also verify the line D_1H of the graph shown in Figure 1 (l.c.).

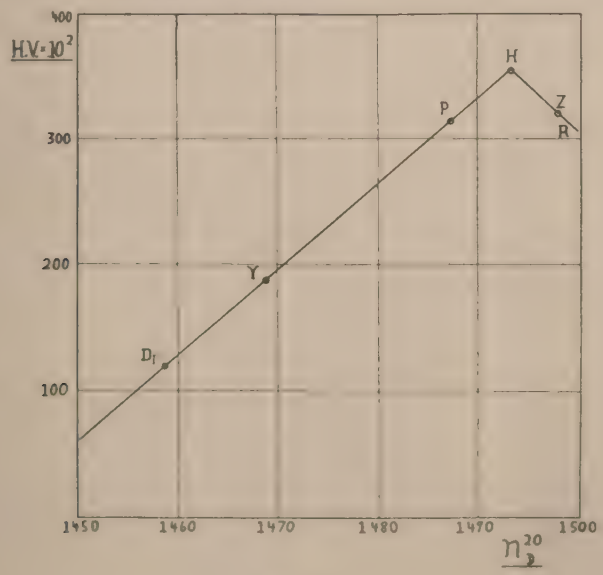


FIG. 1.

[1] Fisheries Research Board of Canada, Halifax, Nova Scotia.
[2] British Rubber Producers' Research Association, Welwyn Garden City, England.

TABLE I

Source and Method of Isolation of Unsaturated Methyl Esters

Sample No.	Name — Methyl:	Source and Method of Isolation	Reference
1	Oleate (9-octadecenoate)	From olive oil by the fractional crystallization method.	(6)
2	Petroselinate (7-octadecenoate)	From coriander seed oil by fractional crystallization.	(1)
3	Linoleate (9, 12-octadecadienoate)	From tobacco seed oil by chromatographic separation on silicic acid.	(7)
3a	Linoleate (9, 12-octadecadienoate)	From cottonseed oil through debromination followed by molecular distillation.	(9)
3b	Linoleate (9, 12-octadecadienoate)	From cottonseed oil through the same process as 3a.	(6)
3c	Linoleate (9, 12-octadecadienoate)	From cottonseed oil by chromatographic separation on alumina.	(8)
4	Linolenate (9, 12, 15-octadecatrienoate)	From Linseed oil by chromatography on silicic acid.	(7)
4a	Linolenate (9, 12, 15-octadecatrienoate)	From Linseed oil by debromination followed by molecular distillation.	(9)
4b	Linolenate (9, 12, 15-octadecatrienoate)	From Linseed oil by the same method as 4a.	(6)
5	Arachidonate (6, 10, 14, 18-eicosatetraenoate)	From beef suprarenal gland lipids by fractional crystallization	(4)
6	Docosahexaenoate	From cod liver oil, haddock liver oil, and sardine oil, by molecular distillation.	(3)

This line is defined by the co-ordinates of the two points D_1 and H:

$$D_1\begin{cases} n_D^{20} = 1.4589 \\ H.V. \times 100 = 120 \end{cases} \qquad H\begin{cases} n_D^{20} = 1.4930 \\ H.V. \times 100 = 355 \end{cases}$$

rom the equation of this line the following empirical expression can be derived:

$$n_D^{20} = 1.44163 + H.V. \times 0.0145 \qquad (I)$$

this expression H.V. represents the hydrogenation value (mg. of hydrogen cessary to saturate 1 g. of compound). The iodine value is linked to the hydro-nation value by the following simple relationship:

$$H.V. = I.V. \frac{1.008}{126.93} = I.V. \times 0.79414 \times 10^{-2} \qquad (II)$$

In Table I are listed a series of methyl esters, their origin, and method of olation.

In Table II are listed the I.V. and refractivities published for the same mples; their H.V. calculated from the I.V. using relation (II). In two cases amples 3 and 4) the refractivities were given for 25°C., and it was necessary extrapolate for 20°C., using the known increment: 0.00038/degree (6, 10).

Table II shows moreover the values of n_D^{20} calculated by expression (I). The lculated values show little deviation from the experimental one.

There remains little doubt that the relationship expressed by relation I dicates definite structural characteristics common to all the esters examined; y material which does not follow this rule must be structurally different or ust contain appreciable amounts of structurally different material. This tter type of material would be represented by points falling below the line H, and these must include the points situated on the HR branch of the curve own on Fig. 1.

TABLE II

Comparison Between Actual and Calculated Refractive Indices n_D^{20} of the Samples of Methyl Esters Listed in Table I

No.	I.V.	H.V.	n_D^{20}		Deviation
			Calculated	Actual	
	86	68	1.4515	1.4517	−0.0002
	86	68	1.4515	1.4508	+0.0007
	173	137	1.4615	1.4611	+0.0004
	173	137	1.4615	1.4613	−0.0002
	173	137	1.4615	1.4616	+0.0001
	173	137	1.4615	1.4613	−0.0002
	260	207	1.4716	1.4726	−0.0010
	260	207	1.4716	1.4709	+0.0007
	260	207	1.4716	1.4711	+0.0005
	319	253.5	1.4784	1.4798	−0.0014
	445	355	1.4930	1.4930	+0.0000

The new evidence strongly supports the views expressed previously and nfers an enhanced interest on the hydrogenation value/refractivity relation-ip of naturally occurring unsaturated fatty acids.

It is very likely that similar relationships exist between the unsaturation lues and the refractive indices of other esters of the unsaturated, naturally curring fatty acids. These would include the glycerides or mixtures of ycerides.

It is interesting to note in this connection that empirical relationships between I.V. and refractive indices have been found for samples of oils of natural origin (5), but these are not to be confused with the relationship described by the present paper. The relationship for natural oils varies with the type of oil and is only applicable within narrow limits. The presence of variable proportions of saturated constituents accounts for this behaviour.

REFERENCES

1. Chernoyarowa, J. Gen. Chem. U.S.S.R., *9*, 149 (1949).
2. Farmer, E. H., and Vandenheuvel, F. A., Soc. Chem. Ind., *57*, 24 (1938).
3. Farmer, E. H., and Vandenheuvel, F. A., J. Chem. Soc. *1938*, 427.
4. Herb, S. F., Riemenschneider, R. W., and Donaldson, J., J. Am. Oil Chem., *28*, 55 (1951).
5. Hunt, W. H., Neustadt, M. H., Shurkus, A. A., and Zeleny, L., J. Am. Oil Chem., *28*, 5 (1951).
6. Mattil, K. F., and Longenecker, H. E., Oil and Soap, *21*, 16 (1944).
7. Riemenschneider, R. W., Herb, S. F., and Nichols, P. L., J. Am. Oil Chem., *26*, 371 (1949).
8. Swift, C. E., Rose, W. G., and Jamieson, G. S., Oil and Soap *20*, 249 (1943).
9. Vandenheuvel, F. A. (unpublished).
10. Wyman, F. W., and Barkenbus, C., Ind. Eng. Chem., Anal. Ed., *12*, 658 (1940).

[Received June 11, 1951]

[Reprinted from THE JOURNAL OF THE AMERICAN OIL CHEMISTS' SOCIETY, March 1953 Issue, Vol. XXX, No. 3, Pages 104-110]

A New Alkali Isomerization Procedure

F. A. VANDENHEUVEL and G. H. RICHARDSON,
Fisheries Research Board of Canada,
Halifax, Nova Scotia

THE standard procedure described in the 1948 Report of the Spectroscopy Committee (2) has many generally recognized shortcomings. Improvements have been proposed. We are indebted to Brice *et al.* (1) for more adequate spectroscopic constants and for a pertinent suggestion as to the optimum time of reaction. The application of the procedure remained however what it was originally; a long, complicated, exacting series of manipulations requiring above-average skill and experience. Even under the best circumstances the accuracy is in no way remarkable. As a tool in the kinetic study of the alkali-isomerization reactions it is poor. A time lag results from the fact that the sample does not dissolve instantaneously on coming in contact with the hot reagent. This lag cannot be determined because of undefined variations, resulting from the manual handling of the reaction tubes at the time solution takes place. Clearly there was a need for:

a) An apparatus allowing simultaneous application of an identical treatment to samples and blanks

b) A procedure which would eliminate the time lag resulting from delayed solution

c) A procedure allowing the same treatment to be easily reproduced from run to run.

Moreover, to make it a more practical, reliable, and accurate method, steps should be eliminated entirely or extensively modified. Among the steps to be eliminated were:

a) The cumbersome and time-consuming transfer of the reaction mixture to the volumetric flasks

b) The use of specially purified absolute alcohol as solvent.

Printed in U.S.A.

Among the features needing improvements were:

a) The nitrogen purifying train
b) The handling of the reagent.

The authors undertook the present work in order to find a solution to these problems. The present article describes the outcome as follows:

Under Apparatus:

a) A reagent handling unit allowing preparation, storage, and dispensing
b) A new nitrogen purifying train
c) A new alkali-isomerization apparatus.

Under Determination of Δ m:

A procedure for the determination of a correction, Δ m, bearing on the reaction time and allowing lag effects to be eliminated.

Under Suggestion for a New Procedure:

A simple protocol, allowing the faithful reproduction of conditions.

Apparatus

Figure 1 shows the relative position of each piece of apparatus on the laboratory table (top view). The top half represents the nitrogen purifying train; in the lower half the isomerization apparatus proper is shown at the right while the reagent dispensing unit is shown at the left.

A few details of the isomerization apparatus are indicated: heating bath A, cooling bath B with cooling water inlet C and outlet D, thermoregulator E,

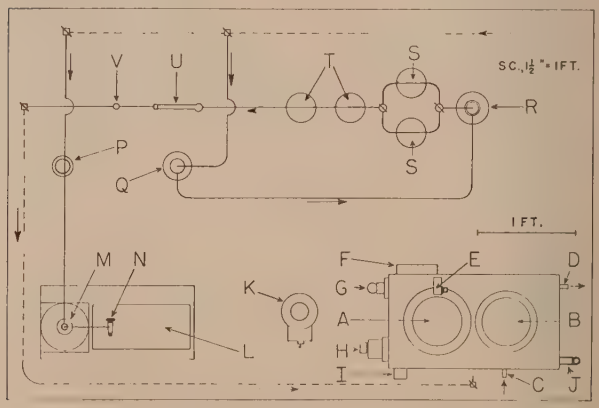


Fig. 1. General lay-out of isomerization equipment.

duplex female outlet F, pilot light G, selector switch H, relay I, and support J. K is a standard Variac transformer.

Reagent dispensing unit L is composed of the dispenser proper M, installed on a shelf at the proper height to be used in connection with scales L (torsion balance) on which the reagent is weighed out. The dispenser is connected to the nitrogen line through a mercury safety valve P.

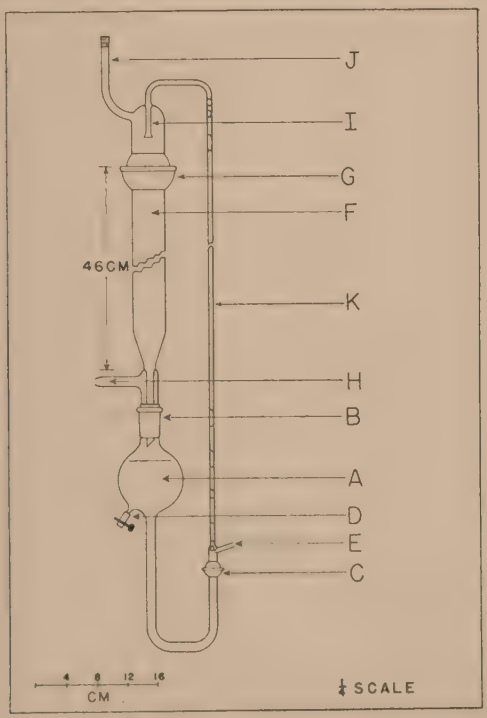


FIG. 2. Nitrogen scrubber.

The purifying train, following the direction of the stream indicated by arrows, is composed of wet nitrogen scrubber Q, safety bottle or trap R, 10% sulfuric acid absorbers S installed in by-pass, concentrated sulfuric acid absorbers T, soda-lime tube U, flow meter V (Greiner No. C10947 A Florator), and a utilization line ending at the position shown.

The solid lines represent glass connection, the dashed ones small bore brass pressure tubing. The valves indicated by squares are small brass needle valves. The nitrogen supply comes through a standard pressure regulator from a bottle not shown.

The nitrogen scrubber is shown in Figure 2. Reservoir A contains a solution made of equal parts of concentrated aqueous ammonia and saturated aqueous ammonium chloride solution to the level indicated.

Joints B (℉ 24/40), C (℉ 18/9), and G (℉ 65/40) allow convenient assembling and cleaning; the latter two are maintained in position by appropriate clamps (not shown). An outlet D is provided for emptying the spent solution. The gas inlet E leads the nitrogen to the 6-mm. section gas-lift K while the nitrogen, after passing through the copper shavings filling F, leaves the scrubber through H for the absorption train.

The copper shavings (Chore Girl) are kept wet by the intermittent spray of solution issuing from I. A filling tube J allows the replacement of the spent solution.

The oxygen-free nitrogen is stripped of water and ammonia in the rest of the train. Most of the ammonia, if not all, is retained in the 10% sulfuric acid absorbers. The solution in these, when saturated, tends to clog the inlet tube, hence the by-pass.

The reagent dispenser is shown in Figure 3. It consists of a reservoir A (2-litre borosilicate glass bottle with 24/40 ℉ neck B), and a tube C which functions either as bubbler (preparation) or siphon (dispenser). A side tube D allows nitrogen pressure to be exerted to lift reagent in C for delivery, through the flow regulating stopcock E, to tip F. As seen from the figure, the tip is protected by a glass spring-fastened, ℉ cap during storage. Bottle A can be heated by a 250-watts resistor H. The latter is maintained in position by two circular collars G, tightly fastened to the bottle. Asbestos-insulated leads I allow connection to a Variac transformer. Bottle A rests on a glass wool pad K. The same material is used to stuff the top space as shown.

For the reagent preparation, siphon C is lifted high enough to allow a thermometer to be slipped into neck B, and the oxygen-free nitrogen source is connected to tip F. Variac-controlled heating is then applied to H. The details of the preparation are those specified in the standard procedure.

The isomerization apparatus proper is shown in Figure 4. In the top view (I) A represents the aluminum heating bath, B the cooling bath of equal diameter and depth. The water leads for the cooling bath are respectively shown as C and D. A De Khotinsky thermoregulator E, pilot light G, relay I, condenser K, and thermoregulator switch L form the elements of a conventional thermoregulating circuit.

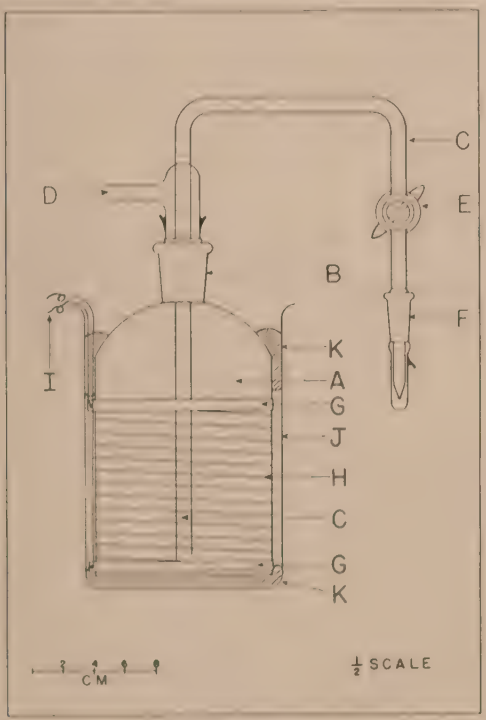


Fig. 3. Reagent dispensing unit.

A three-position switch H allows the heating element (not shown) to function on low, medium, or high while F allows the current used to be drawn either from the mains or from a Variac transformer connected to the mains.

The parts constituting the heating circuit are fastened at convenient locations to the wooden sides of the box holding the two baths. The latter (Figure

4, II) are supported by their rims from the top of the box. This top is a piece of heat- and chemical-resistant white Arborite. The box is divided into two compartments, the one holding the heating bath being stuffed with glass fiber M for insulation. As section WX shows, the thermoregulator well opens to the inside of the bath.

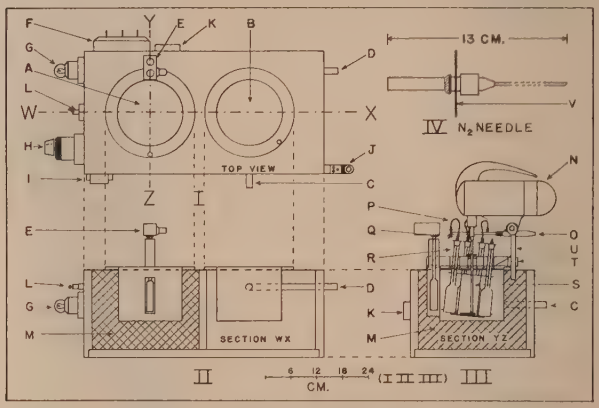


FIG. 4. Isomerization apparatus.

Section YZ (Figure 4, III) shows, in relation with parts already described, the position of the bottle carrier and driving assembly in the course of operation. Motor N, nitrogen manifold O, bottle rack S, and cover T constitute one whole unit which can be lifted from, or placed in either of the baths when held by the motor handle. The motor is a standard Mix-Master motor, which has proved very convenient. It is fastened to the cover through arm U, fixed in socket T by a set screw. The end of U is used as a plug, which can be slipped in socket J (Figure 4, I). The latter is fastened through a bracket to the top-right corner of the box; it allows the motor and bottle rack unit to be hung in a convenient position for the operation of inserting or removing the bottles.

Figure 4, III shows also how circular nitrogen manifold O, made of brass tubing, is connected by surgical rubber tubing P to needles Q; these needles are prevented from falling into the bottles by light metal disks V (Figure 4, IV).

Figure 4, IV shows the simple construction of a nitrogen needle. The needles used are 19-gauge, 3½-

inch Vita lumbar puncture needles, to which a small length of connecting brass tubing has been silver-soldered.

Figure 5 depicts the heating unit in more detail. In the bottom of aluminum bath A is welded the heating element B (Graham No. 623, 1250 W, 3-heat Lo-Lag). The latter is connected to the outside circuit by asbestos-insulated wire, to which it has been silver-soldered. Thermoregulator well C is welded to the side of the bath with which it communicates by a wide port P. That part of C protruding above the bath is cylindrical while the part welded to the bath side is wider and presents a U-shaped cross section.

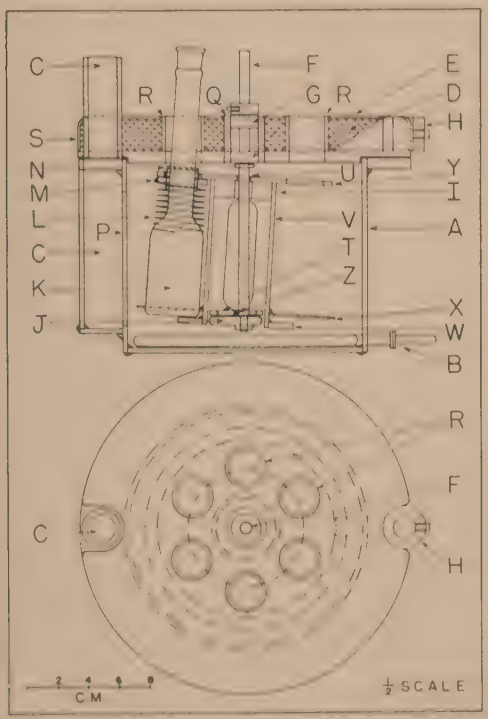


FIG. 5. Details of heating unit.

Three set-screws (not shown), located laterally at the top of C, allow the thermoregulator to be firmly and centrally held in the well.

Cover D is made of ¼-inch aluminum plate. The periphery of the disk is first machined on one face to form a ⅛-inch recess fitting the bath rim. A hole is then bored in the center and a piece of aluminum tubing Q welded on. Q houses ball-bearings G. Two diagonally opposite cut-outs are then made. One is to fit around the protruding end of well C; to the other is welded the set-screw fitted plug H, which is later to receive the motor arm. Six holes are also bored to allow the passage of the bottle necks. A piece of thin-walled tubing, R, is welded to the edge of each hole. The space between tubes is filled with glass fiber and the latter maintained in position by a top cover E, made of thin aluminum sheet stock cut out to match the design of the bottom part. E is fixed by a few spot welds. Finally a light aluminum strip S is welded all round top plate E, thus forming the side of insulated cover D. Direct contact between top and bottom metal surfaces is thus restricted to a few spot welds.

Driving shaft F is fastened to insulated cover D by one fixed (lower) and one adjustable collar as shown. F is linked to the motor by a strong coupling. The other extremity of F is threaded. Brass eccentric J screws on this thread; the lock-nut prevents J from unscrewing when in operation.

Eccentric J supports the bottle rack through collar T. When the machine is in operation, the bottle rack is given a swirling-rocking motion, centered on U. The carrier is prevented from being entrained in a circular motion by the bottle necks leaning on the cover.

When the motor is running and lock-nut is held and prevented from turning, it unscrews immediately. The bottle rack can then be pushed upward just enough to make the eccentric appear. When the latter is unscrewed, the rack can be slipped down and removed. It is then fully accessible and allows the bottles to be inserted or removed as the case may be. Remounting the rack on the shaft is done just as simply.

The carrier rack is constructed from a length of aluminum tubing V, lightened by four oval cut-outs. To the bottom edge is welded a circular shelf W, lightened by multiple perforations.

Just above W is welded a wider circular disk or bottle spacer X, made of thin aluminum sheet stock; this bears six holes, the diameters of which fit the ex-

ternal diameter of the bottles K. The top disk Y of the rack bears corresponding smaller holes and is perforated in its center by hole U; the diameter of U is larger than the shaft diameter to allow for rocking motion of the carrier. A collar M and attached spring L prevent upward motion of the bottle. Lateral motion is prevented by a collar N permanently fastened to the neck of the bottle. N will slide on the neck of the bottle only when pushed. Two diametrically opposed pins Z fasten collar T to the inner wall of V yet allow it to follow the rocking motion.

Inserting a bottle is accomplished as follows. Slip N down on neck, slip ring M and spring L over neck; slip neck through hole in top disk of rack; slip bottle bottom through hole in bottle spacer until it rests on W; push N upwards until it occupies the position shown in Figure 5.

The heating bath is filled with smokeless Dow Corning Silicone fluid 550. When the rack is not immersed, the level is at 60 mm. from the top of the rim. With the rack immersed the spiral of the thermoregulator is completely submerged and the level reaches the necks of the bottles.

Figure 6, I shows the construction of collar N. It is made of a grooved aluminum cylinder A. The latter is sawed lengthwise into two equal parts which are fitted around the bottle neck B and held together by a few turns of chromel wire located in grooves C.

Figure 6, II shows the long tweezers E, made of thick copper wire D, used to slip the cups F containing the samples in the reaction bottles. Tweezers are necessary to avoid splashing. When the cups contain solid fats, this precaution can be omitted.

Determination of Δ m

The standard procedure specifies that the cup containing the sample be dropped into the reaction tube containing the hot reagent.

Our kinetic study of the alkali-isomerization reactions, soon to be published, has shown among others, the following facts:

a) The activation energy of all the reactions involved is constant over a wide range of temperature and equal to 27.6 K cal. per mole; the velocity increases 1.08 times for every degree rise in temperature.

b) At 180°C. the reactions involving linolenic acid, for example, are practically completed after 7 minutes; after only 2 minutes about two-thirds of the original material

has been transformed. The reaction rates are thus very high. Delayed solution, in such cases, exerts an appreciable distorting effect which renders meaningless, for kinetic purposes, results obtained in this way. The picture is even more complicated by variations due to a human factor since the standard procedure specifies that solution be helped by manual swirling of the reaction tubes. This state of affairs also affects the reproducibility of analytical results.

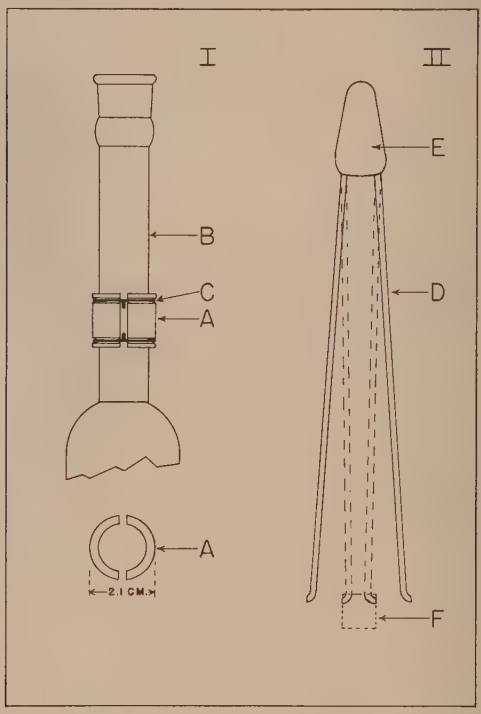


FIG. 6. Bottle fitting and tweezers.

In the new procedure the sample is dissolved at any convenient temperature below 100°C. At 80°C., for example, solution is completed for most fatty materials in less than two minutes under the efficient and sustained agitation provided by the apparatus. At the same temperature the reactions are about 1,000 times slower than at 180°C.; no appreciable polyene formation results from this treatment.

The homogeneous reaction mixture is then brought rapidly to R°, the temperature selected as reaction temperature, maintained at R° for m minutes, and then rapidly cooled down to room temperature. In practice, the thermal effects corresponding to the heating up and cooling down phases are appreciable. These effects, in contrast with those resulting from the delayed solution described above, can be easily and quantitatively determined as follows:

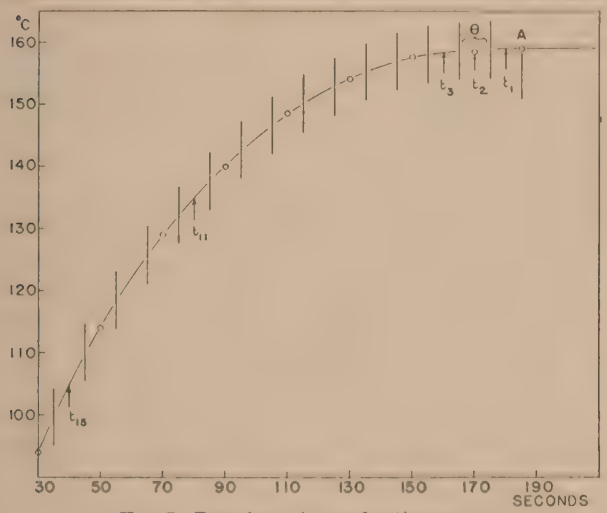


FIG. 7. Reaction mixture heating curve.

Figure 7 represents the time temperature curve of a reaction mixture. In this case $R° = 159°C$. Point A corresponds to the moment 159°C. has been reached. Let us divide the curve into short equal intervals θ (here 10 seconds or $\frac{1}{6}$ in our time unit), starting from point A down. The temperatures corresponding to the middle of each section $t°_1$, $t°_2$, $t°_3$, ... $t°_n$ are read from the curve. The ratio of the reaction velocity at any of those temperatures to the velocity at 159°C. is

$$f_n = 1.08^{-n}$$
$$\text{with } n = R° - t°_n \qquad (1)$$

Owing to the particular kinetics of the reactions involved, it can be demonstrated that

$$\Delta m = \theta \Sigma_1^n f_n \qquad (2)$$

Where Δ m is the length of time, expressed in minutes, the reaction mixture would have to be heated at 159°C. to reach the state corresponding to point A. The values of f_n can be obtained from a plot of the function $f_n = 1.08^{-n}$. In our example:

$$\Delta m = \tfrac{1}{6} (1 + 1 + 0.962 + 0.900 + 0.800 + 0.635 + 0.590 + 0.470 + 0.375 + 0.285 + 0.190 + 0.115 + 0.065 + 0.040)$$

$$\therefore \Delta m = 1.24 \text{ min.}$$

The same procedure is applied to determine the Δ m corresponding to the cooling phase. It follows that if a specified time M of heating at R° is to be observed, m, the time of heating at R° proper can be adjusted so that

$$M = m + \Delta m$$

The value of Δ m and consequently the value of m. is accurate under the following conditions:

a) θ should be small; for all practical purposes $\theta = 10$ seconds is satisfactory.

b) Heating and cooling phases should be short. This can be accomplished, for example, by more rapid agitation or by using bottles made of thinner glass.

c) The time-temperature curve should be established with care; this applies especially to the 15° range below R°.

The advantage of the method lies in the fact that the final result is independent of the conditions under which the operation has been carried out. This eliminates variations due to the human factor as well as those resulting from apparatus characteristics.

The method attains its full practical value when used in conjunction with the new isomerization apparatus. Using this apparatus, it is easy to reproduce a given set of conditions from run to run.

In such cases the variations of Δ m are small enough to be considered negligible for most purposes.

It follows that the determination of Δ m need be made only once, and for all, for a given apparatus and a given temperature R°.

Suggestions for a New Procedure

The complete description of a new procedure should include the specification of the optimum time M, the optimum temperature R°, the corresponding spectroscopic constants, and the set of equations allowing the results to be calculated. This has to await the results

of the application of the new method to pure natural acids or esters therefrom. If the old reaction temperature is maintained and a reaction time of 45 minutes is imposed, little change will result in the absorption coefficient for linoleic acid, but an extensive readjustment may affect the absorption coefficient of linolenic and arachidonic acids. Moreover our kinetic study of debromination acids indicates that 180°C. is not the optimum temperature for these two acids.

Meanwhile the description of the new method has to be restricted to the experimental procedure itself. The following is a step-by-step description of a simple and practical protocol of operations. It should be evident from the foregoing that some modifications could be introduced without changing the final results in any way.

The description is divided in Preliminary Steps, which are followed only once and for all, and General Procedure, covering the analytical protocol proper.

Preliminary Steps

a) Select for uniform size and weight a series of borosilicate glass Stoddard bottles (see Commercial Standards CS 3-28 of the National Bureau of Standards).

b) Add to each bottle an empty 1-ml. borosilicate glass cup (Cenco 28772, for example). Add exactly 55.00 g. distilled water to each bottle and carefully mark the position of the meniscus.

c) Fit each bottle with a collar N (Figure 6). Make a tare corresponding to 6 g. + the weight of each collar-fitted bottle without stopper. Precision ± 0.01 g. Number flasks and corresponding tares.

d) Take 6 of these bottles. Place one on balance pan, the corresponding tare on the other pan. Equilibrate by adding glycol to the bottle. Repeat with the five others. Insert all six bottles in the isomerization apparatus rack. Fit one of the bottles with a cork which should be equipped with a calibrated thermometer, a nitrogen needle, a sensitive thermocouple, and a slit on the side to allow the nitrogen to escape. Both thermometer bulb and thermocouple junction should be immersed in the liquid. This bottle will become a permanent fixture of the rack. The thermocouple is connected to a calibrated millivoltmeter or to a temperature recorder. The temperature indicated by these instruments will be hereafter called bottle temperature (B.T.).

e) Immerse rack in the heating bath, switch on heater and motor. Adjust speed of the latter to about 250 r.p.m. Note position of the motor dial. The selected speed will never be changed and should be checked occasionally.

f) Find circuit adjustment allowing smooth control of temperature R°. This means both thermoregulator setting and current. Depending on temperature R°, a combination of "low" or "medium" with a particular voltage

V as shown by the Variac dial will be found. With this combination the fluctuations of the bottle temperature (B.T.) should not be larger than 0.2°C. at R°. Note this indication V of the Variac dial and the intensity I of the current used for future check. If wide fluctuations of the mains voltage are expected, connect the system to voltage regulator.

g) Find a starting temperature (S.T.). The purpose is to shorten the heating period by immersing the bottles in a bath brought to S.T. $>$ R°. S.T. should be the highest possible temperature of the bath which will not cause B.T. to rise above R° at equilibrium.

Proceed as follows. After the heating current is adjusted for control (V, I), switch off thermoregulating circuit (switch L, Figure 4) and allow the temperature to rise. From time to time stir the oil with a thermometer and note temperature. When the latter has reached a temperature about 10° higher than R°, immerse the rack equipped with all the bottles at room temperature and immediately switch on motor. Then switch on thermoregulating circuit and observe B.T. If, on reaching R°, B.T. does not rise above R° and thermoregulator smoothly takes over control, try higher starting temperatures until the highest possible is found. Note S.T.

h) Repeat the operation starting with S.T. This time start stop watch as soon as rack is immersed. Note B.T. every 20 seconds until R° has been reached. After the bottles have been maintained at R° for a few minutes, switch off motor and immediately lift rack from bath. Let rack rest on edge of bath for 90 seconds; note B.T. every 20 seconds. This step is meant to allow drainage and so cut losses in expensive silicone oil. When 90 seconds have elapsed, immerse rack in cooling bath, start motor immediately, and turn on cooling water stream. Note B.T. every 20 seconds. Calculate global Δ m from the three time-temperature curves. The specified reaction time being M, deduce

$$m = M - \Delta m$$

Check by repeating operation. Keep note of time at which B.T. reached R° (point A, Figure 7) and of temperature attained at end of 90 seconds drainage period.

The preliminary steps are completed. Keep stoppered and at hand three of the glycol-containing bottles. Analyses should always be conducted with rack fully occupied. The three glycol bottles will be used as dummies to fill unoccupied rack space.

General Procedure

a) Start nitrogen train and turn heating on "high."

b) Weigh samples.

c) Equilibrate bottles with corresponding tares by adding required amount of reagent $\pm$ one drop. Each time a bottle is supplied with reagent, introduce cup containing sample using tweezers and slip tube leading nitrogen into neck. Add reagent to next bottle. When this is ready,

stopper first bottle and slip nitrogen tube in next. Proceed in this way until all bottles are supplied. An empty cup is added to the blank bottle.

d) Switch nitrogen stream to manifold and place bottles in rack. Fill empty spaces with dummies. Slip nitrogen needles in bottle necks and keep flow at 300 cc./minute for five minutes.

(At this point it is possible with most fatty materials to pass directly to the next step (isomerization proper) because complete solution in the reagent will occur during the early stages of heating while the temperature of the reaction mixture is still under 100°C. For others however, the solid fats in particular, the following intermediate steps should be included: fill bath B with hot water, immerse the bottle-laden rack, and switch on motor; when solution is complete, turn on cold water to bring to room temperature.)

e) The temperature in the bath should now be near or have attained R°. Switch off thermoregulating circuit and set current at control value I. Let temperature rise to S.T. At last stages stir bath with thermometer. When S.T. is attained, introduce rack in bath, start motor and stop watch; switch on thermoregulating circuit.

f) Shortly after, reduce nitrogen flow to 160 cc./minute (30 cc./min./bottle). Observe B.T. and note time B.T. reaches R°. Let reaction proceed at R° for m minutes.

g) After this time has elapsed, stop motor, lift rack from bath, and let it rest on edge for 90 seconds. Note B.T. at end of period.

h) Immerse rack immediately in cooling bath and start motor. Turn on cooling water stream. Increase nitrogen flow to 300 cc./min. Wait 5 minutes.

i) Stop motor, lift rack from bath, hang rack to bracket J (Figure 4). Wipe bottles and rack with tissue paper, remove needles and stopper bottles one by one, remove rack and remove bottles from rack.

j) To one of the bottles add about 40 ml. 95% ethyl alcohol, slip nitrogen tube in neck; wait about one minute, stopper, and proceed similarly with all bottles. Shake all bottles vigorously. Examine from time to time for complete solution of reaction mixture and complete flocculation of silicates. Use shaking machine if available.

k) Make up to the 55-ml. mark, with 95% ethyl alcohol, stopper and homogenize contents of each bottle. Centrifuge about 40 ml. from each bottle in nitrogen-filled, stoppered centrifuge bottles. Use angle centrifuge at moderate speed (1,500 r.p.m.) for 15 to 20 minutes. At the end of this period the precipitate sticks to the bottom, leaving perfectly clear supernate.

l) Use clear liquid for further dilutions and proceed as specified by the standard method.

Experimental Results

Table I shows a series of results obtained with pure methyl linoleate and linolenate (no corrections needed). They are truly representative of a larger set

TABLE I

Alkali Isomerization of Debromination Methyl Linoleate and Methyl Linolenate

(6.5% KOH-Glycol for Time and at Temperature Indicated)

Sp.*a*, 1 cm., 1 g. per 1000 ml. at Indicated Wave Lengths

Conditions	Bottle A	Bottle B	Δ B	Run Average	Δ R	Material	Mean Δ B	Mean Δ R
	Sp.*a*	Sp.*a*		Sp.*a*				
20 min. 149° C. λ = 233 mμ	26.86 26.70	26.55 26.65	+0.30 +0.05	26.70 26.68	+0.01 +0.01	Methyl Linoleate	+0.18	0.01
60 min. 149° C. λ = 233 mμ	57.20 56.80 57.20 57.40 57.70 57.25	57.20 56.55 56.75 56.50 57.50 57.15	+0.00 +0.25 +0.45 +0.90 +0.20 +0.10	57.20 56.67 57.00 56.95 57.60 57.20	+0.10 −0.43 −0.10 −0.05 +0.60 +0.10	Methyl Linoleate	+0.3	0.2
40 min. 164° C. λ = 233 mμ	77.10 77.60 77.35 77.95	76.55 76.70 lost 77.10	+0.55 +0.90 ..... +0.85	76.83 77.15 77.35 77.53	−0.45 −0.13 +0.07 +0.25	Methyl Linoleate	+0.75	0.225
80 min. 129° C. λ = 233 mμ	47.80 47.55	48.00 48.20	−0.20 −0.65	47.90 47.88	+0.01 −0.01	Methyl Linolenate	−0.43	0.01
80 min. 129° C. λ = 268 mμ	35.40 35.65	35.80 35.70	−0.40 −0.05	35.60 35.67	−0.035 +0.035	Methyl Linolenate	−0.23	0.035

of results (over 350) which have been obtained through the procedure just described. They have been selected from those corresponding to a rising portion of the time-absorption coefficient curves. Results corresponding to the flat, post-maximum portion of the curves present appreciably smaller deviations as would be expected.

The results are shown listed in pairs, each pair representing duplicate analyses performed in the course of the same run; Δ B shows the difference between the result obtained using bottle A and that obtained using bottle B. All determinations involving methyl linoleate were carried out using the same pair of bottles. A different pair was used for methyl linolenate. The values listed under Δ R represent the deviation of the run average (average of twin duplicates) from the average value for the complete series of duplicates.

It must be pointed out that the supply of freshly prepared esters was kept in several 1-g. evacuated ampoules and in the cold. For more immediate use one ampoule would be opened and its contents stored in a tight-fitting hypodermic syringe equipped with a long fine needle. Between deliveries the stylet supplied with the needle was kept in the latter. This procedure was found more practical and safer than keeping the supply under nitrogen. The specific absorption coefficient of esters kept under nitrogen showed an appreciable change over a period of two weeks, due presumably to the cumulative effect of short periods of exposure to oxygen occurring every time the container was opened for the withdrawal of a sample and despite the fact that the blanket of nitrogen was renewed immediately after the weighing. No change was observed after two weeks when a syringe was used.

Discussion

The consistency of the sign affecting Δ B shows a definite difference in bottle characteristics. The relative importance of mean Δ B against mean Δ R suggests that these differences play an important role and that more consistent results could be obtained if bottles of more uniform characteristics were used.

As they are, the results show a definite improvement over those obtained by the old procedure. As mentioned above, Δ B is much smaller among results corresponding to the flatter portion of the time-absorption coefficient curves; the deviations of Δ R are

also smaller, although to a lesser degree. The standard Δ R deviation for such results is about 0.3%. This low standard deviation is proof of the reproducibility of conditions from run to run obtainable through this procedure. The proof for the validity of the Δ m procedure was found in the homogeneity of results obtained over a wide range of temperatures and times, all of which fitted the same simple kinetic pattern.

The wet deoxygenator described above is an adapted version of the apparatus proposed by Uhrig *et al.* (3) for oxygen determination in hydrocarbons. It is more efficient than the furnace used in the standard procedure. The presence of oxygen in the blanketing nitrogen has long been recognized as a source of error. Intrusion of oxygen into the bottles can readily be detected, unfortunately after treatment, by the browning of the normally colorless bottle contents.

Note the comparatively much smaller amount of nitrogen used for blanketing each bottle (30 cc. against 50 to 100 in the standard method). The reason for this lies in the use of long-necked bottles instead of the wide tubes as in the standard method. Better and more uniform nitrogen distribution is ensured by the use of standard-gauge nitrogen needles instead of the arrangement formerly proposed. The needles are also more practical leads than the fragile glass ones used hitherto.

The advantages of the Stoddard bottles are not limited to efficiency in nitrogen blanketing. The Ⓣ stoppered, narrow, graduated neck allows the first dilution of the reaction mixture to be effected in the reaction bottle itself and so eliminates the oxidation hazard of the otherwise cumbersome transfer described by the old procedure. Further the flat bottom of the Stoddard bottle promotes efficient stirring and offers a large heating area.

The elimination of specially purified absolute alcohol introduces, it is true, an extra step of centrifugation. The work involved is not considerable however and is easily compensated by the elimination of manipulations and expense involved in the preparation of the former type of solvent.

Note also the reduction in the quantity of reagent used (6.00 g. instead of 11.0 g.) which is ultimately a time and labor saving modification. The apparatus described for handling the reagent allows the latter to be prepared, stored, and dispensed under continuous protection. In combination with a torsion balance it

constitutes a practical unit allowing a fast and clean weighing operation. In relation to reagent handling it should be pointed out that accurate weighing is unnecessary for routine analytical work. The authors found that filling to a predetermined mark corresponding to the volume of 6 g. reagent was sufficiently accurate. They observed that up to 1.5 g. excess reagent in a sample bottle, while the blank bottle contained the normal amount, did not affect appreciably the results corresponding to the flat, post-maximum region of the time-absorption curves. For samples leading to very small absorption values or for kinetic work, the reagent has to be measured more accurately.

Simultaneous treatment of all samples and blanks not only eliminates an important source of error, but appreciably facilitates the operator's task.

To summarize, the new procedure represents an improvement in accuracy, practicality, and reliability.

Acknowledgment

We are indebted to H. E. Power and R. C. Edmonds of this Station for their contribution to the design and construction of the new isomerization apparatus and to R. P. A. Sims of the National Research Council, Ottawa, for a suggestion concerning the nitrogen scrubber.

REFERENCES

1. Brice, B. A., Swain, M. L., Herb, S. F., Nichols, P. L. Jr., and Riemenschneider, R. N., J. Am. Oil. Chem. Soc., *29*, 279-286 (1952).
2. Report of the Spectroscopy Committee, Nov. 15, 1948, J. Am. Oil Chem. Soc., *26*, 399-404 (1949).
3. Uhrig, K., Roberts, F. M., and Levin, H., Ind. Eng. Chem., Anal. Ed., *17*, 31 (1945).

[Received August 28, 1952]

342

351

(*Reprinted from Nature, Vol.* 171, *p.* 344, *February* 21, 1953)

Ribose and the Maillard Reaction in Fish Muscle

THE occurrence and control of the Maillard reaction has been studied fairly thoroughly in dehydrated milk, eggs, fruits and vegetables; but little information is available concerning its prevalence in flesh foods. It has been shown in previous work that moist fish flesh usually becomes brown during exposure to high temperatures (for example, 120° C. for 1 hr.), and that this alteration is due to reactions of the Maillard type[1]. The nature of the sugar or substance contributing the aldehyde groups essential for these reactions was not ascertained. The present investigation indicates that ribose is responsible.

It was found convenient to determine the relative intensity of browning in heated muscle of white-fleshed fish by use of a Beckman model *DU* spectrophotometer equipped with a reflectance accessory attachment. As an arbitrary standard a 'white' surface made by blending 4 per cent high-viscosity carboxymethylcellulose and 2·5 per cent magnesium carbonate with water was used. The percentage of light reflected from the surface of heated fish samples was referred to this standard set as 100 per cent, a wave-length of 500 mμ being used.

It was found initially that the muscle of the sea fish examined had a total pentose content which often exceeded 1,500 μgm. per gm. of wet weight. This is probably associated with, or derived from, the nucleic acid of fish muscle nucleotropomyosin[2]. Since tests[3] of aqueous extracts of the muscle for deoxyribonucleic acid were negative, it was reasonably certain that deoxyribose was absent, thus verifying other work[2].

For comparative studies, muscle of halibut (*Hippoglossus stenolepis*), which browns very slightly on heating at 120° C. for 1 hr., was compared with that of lingcod (*Ophiodon elongatus*), which, in common with local species of flounders and *Sebastodes*, browns markedly on heating. With lingcod muscle, total pentose, as determined using a trichloracetic acid extract[2], decreased considerably after heating for 1 hr. at 120° C.; but there was no appreciable further loss after an additional 2-hr. heating. On the other hand, with halibut there was very little measurable loss of total pentose even after heating for 3 hr. When 1,000 μgm. of D-ribose was added per gm. of either halibut or lingcod muscle, it could no longer be recovered from the heated flesh. These findings indicated that only free and not combined

pentose was inactivated in heated muscle. In addition, it was found that the ribosides guanosine, uridine and adenosine did not occasion an increase in browning of heated muscle as did ribose itself.

Preliminary attempts to show that free ribose was responsible for browning in heated muscle were not successful, for only small amounts of ribose were found in extracts of muscle which had been dried *in vacuo* over sulphuric acid overnight. Apparently, most of the ribose combines with free amino groups during the brief drying period, and can no longer be extracted. Extracts of the muscle prepared as follows gave a satisfactory recovery of ribose. Fresh or thawed muscle was blended with 9 volumes of absolute ethanol for 1 min., and 30 ml. of the clear filtrate from the alcoholic extract was concentrated to dryness over sulphuric acid *in vacuo*. The residue, which contained lipoidal matter, was mixed with 1 ml. of water, and the solution applied directly to 28-cm. wide sheets of Whatman No. 1 filter paper for chromatographic separation of the ribose. It appeared that fairly satisfactory chromatographic separation could be effected without desalting the solutions.

In quantitative experiments it was found convenient to apply eight 0·02-ml. spots (in successive applications) of the above extracts at 2·5-cm. intervals along the starting line, qualitative control spots of ribose (5–20 μgm.) or muscle extract being placed near the edges of the paper as qualitative 'markers'. Recovery experiments with D-ribose alone and D-ribose plus the lingcod extract were also carried out. The papers were equilibrated and developed for 16 hr. at room temperature with ethyl acetate – acetic acid – water solvent[4]. After evaporation of the solvent at room temperature, the position of the ribosides present was determined by irradiating the chromatograms with ultra-violet light and marking the dark areas with pencil. It is essential that this be done, so that ribosides, which naturally interfere with the pentose determination, are not cut out with the strip used for determining ribose. Strips containing the 'markers' were cut from along the edges of the chromatograms and the location of the ribose ascertained by spraying with aniline oxalate[5] reagent. This qualitative development always gave very pronounced coloured spots with the lingcod extracts and only very faint spots with those of halibut. To determine the ribose quantitatively, strips 5 cm. wide were cut across the papers to include all the zones corresponding to D-ribose, a similar control strip being cut from another area of the paper which contained no riboside zones. The strips were eluted with 16 ml. of water, the solutions passed through

FREE RIBOSE IN HALIBUT AND LINGCOD MUSCLE AND ITS RELATION TO THE BROWNING OF THE HEATED MUSCLE (HEATED HALIBUT MUSCLE = 64 PER CENT REFLECTANCE AND HEATED LINGCOD MUSCLE = 36 PER CENT REFLECTANCE AT 500 mμ)

Material chromatographed	Total muscle ribose (μgm./gm.)	Total muscle ribose after heating 1 hr. at 120° C.	Loss of ribose due to heating (μgm./gm.)	Ribose recovered after chromatographic separation (μgm.)
Halibut muscle extract (0·16 ml. = 0·48 gm. muscle)	{1580 1540 1560	{1530 1526 1528	32	{40 31 35·5
Lingcod muscle extract (0·16 ml. = 0·48 gm. muscle)	{1460 1406 1433	{850 830 840	593	{585 525 555
180 μgm. of D-ribose				{186 191 188·5
80 μgm. of D-ribose plus 133 μgm. (expected) ribose in lingcod muscle extract*				220 (213 expected)

* Calculated from the average ribose content of the lingcod muscle as given in this table.

ultra-fine 'Pyrex' sintered-glass filters to remove small particles of filter paper, and ribose determined by Mejbaum's method[6] using duplicate 1-, 2- and 3-ml. portions. The results of a typical experiment are given in the accompanying table, all figures being calculated on the basis of the wet muscle. It will be seen that the amount of ribose which was recovered from the unheated alcoholic muscle extracts after chromatographic separation corresponds closely with that which disappeared when the muscle was heated for 1 hr. at 120° C. The recoveries of chromatographed D-ribose, and of D-ribose plus lingcod muscle extract, were good.

Though so far D-ribose has not been identified positively by isolation and chemical characterization, it has been observed that only a single spot can be developed when mixed lingcod extract and D-ribose are chromatographed together.

H. L. A. TARR

Pacific Fisheries Experimental Station,
Vancouver 2, B.C.

Aug. 6.

[1] Tarr, H. L. A., *J. Fish. Res. Bd. Can.*, **8**, 74 (1950).
[2] Hamoir, G., *Biochem. J.*, **48**, 146 (1951).
[3] Stumff, P. K., *J. Biol. Chem.*, **181**, 379 (1949).
[4] Jermyn, M. A., and Isherwood, F. A., *Biochem. J.*, **44**, 402 (1949).
[5] Partridge, S. M., *Biochem. J., Proc.*, xlviii (1948); *Nature*, **164**, 443 (1949).
[6] Umbreit, W. W., Burris, R. H., and Stauffer, J. F., "Manometric Techniques and Tissue Metabolism" (Burgess Publishing Co., Minneapolis, Minn., 1945).

Printed in Great Britain by Fisher, Knight & Co., Ltd., St. Albans.

Reprinted from The Norwegian Whaling Gazette 1953, no. 1 pp. 11-15. In Norwegian and English.
Printed in Norway
AS Handelstrykkeriet, Sandefjord

Preliminary Report on the Growth of Finback Whales from the Coast of British Columbia

By Gordon C. Pike
Pacific Biological Station Nanaimo. B. C.
Fisheries Research Board of Canada

The purpose of this brief preliminary report is to provide information on the growth of finback whales from the coast of British Columbia and to compare this with the growth of finbacks from other localities. The information is based on the examination of 471 finbacks taken at the Coal Harbour whaling station on Vancouver Island during the 1949, 1950 and 1951 summer seasons.

Various investigators have given evidence that the growth of finbacks from the northern hemisphere is less than that for the southern hemisphere (True, 1904; Ruud, 1945; Omura, 1950 and Jonsgård, 1952). Studies on finbacks from Norway, Newfoundland and Japan have shown that the females attain sexual maturity at average lengths of about 60 feet, and the males at about 58 feet. Antarctic finbacks, which have been intensively studied, have been shown to mature sexually at average lengths of 65—67 feet for the females and 63 feet for the males (Mackintosh and Wheeler, 1929. Brinkmann, 1948; Nishiwaki and Oye, 1951). In catches of finbacks from northern waters, lengths seldom exceed 70 feet, whereas in southern waters a large propor-

tion of the catch consists of finbacks longer than 75 feet and some exceed 80 feet in length.

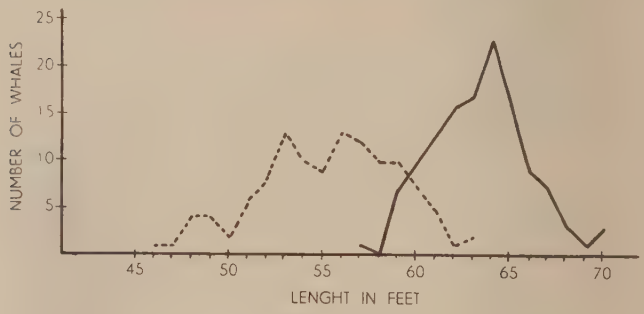


Fig. 1.

Length frequency distribution of female finbacks from British Columbia; 1949, 1950 and 1951.
- - - - sexually immature ; ——— sexually mature.

The length frequency distribution of 242 female finbacks from British Columia is presented in figure 1. The largest immature female is shown to be 63 feet; the shortest mature female is 57 feet. The average length at sexual maturity is approximately 60 feet. Norwegian female finbacks mature sexually at about 61—62 feet (Jonsgård, 1952). Japanese female finbacks mature sexually at about 60—61 feet (Omura, 1950). The slight differences in these averages may be the result of incomplete data. It is clear, however, that the average length at sexual maturity is 5—6 feet shorter for northern than for southern female finbacks. It has been possible to examine only 20 testes histologically for determination of sexual maturity in the males. These few samples indicate that sexual maturity is attained at lengths of 56—61 feet in British Columbia male finbacks. The relationship between testes' weight and body length for 188 males shows a marked increase in testes' weight at lengths of 57—59 feet, suggesting that the estimated averages of 58—59 feet for Japanese males (Omura, 1950) and 58

feet for Norwegian males (Jonsgård, 1952) are applicable also to British Columbia males. These averages are about 4—5 feet shorter than the averages for southern male finbacks.

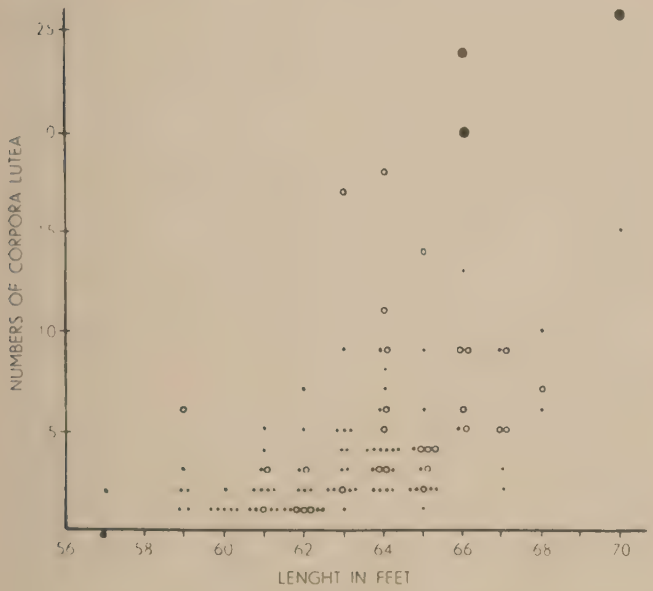


Fig. 2.

Lengths of female finbacks from British Columbia in relation to numbers of corpora lutea and physical maturity.

● **physically mature**

○ **physically immature**

physical maturity not determined.

Figure 2 presents the lengths of 110 sexually mature females in relation to the numbers of corpora lutea in the ovaries. Thirty-two of these whales were examined for physical maturity. In only 3 were the epiphyses found to be completely fused to their respective centra throughout the vertebral column.

Two of these physically mature females were 66 feet in length, one was 70 feet in length. The ovaries contained 20, 24 and 27 corpora lutea, respectively.

All females examined with less than 19 corpora lutea were physically immature. Following sexual maturity growth continues in Antarctic finbacks until physical maturity is attained at average lengths of 72—75 feet for the females and 68—69 feet for the males (Mackintosh and Wheeler, 1929; Brinkmann, 1948; Nishiwaki and Oye, 1951). The attainment of physical maturity in the female has been correlated with the accumulation of 13—15 corpora lutea (Mackintosh and Wheeler, 1929). Examination for physical maturity was made for 23 British Columbia males with lengths ranging from 55 to 66 feet. None of these were physically mature; three were almost mature at lengths of 63, 64 and 66 feet.

It is not possible to assign an accurate average length at physical maturity from this small amount of data, but we may tentatively be assured that the termination of linear growth occurs at much shorter lengths in northern than in southern finbacks. Data from Antarctic finbacks, presented by Brinkmann (1948), show only one of 210 physically mature females with a length of less than 68 feet and only 6 with lengths less than 70 feet.

The mean lengths of 110 females, in relation to the numbers of corpora lutea in the ovaries are presented in figure 3 and compared to data from 383 Antarctic finbacks (Brinkmann, 1948). The mean lengths are shown to increase with increasing numbers of corpora lutea at a decreasing rate until the curves approach a horizontal line. The curves are representative of growth between sexual and physical maturity. Brinkmann's data show an increase in mean length with increasing numbers of corpora lutea up to a length of 74 feet, which corresponds to an accumulation of 10 or more corpora lutea.

Assuming a similarity between northern and southern finbacks in:

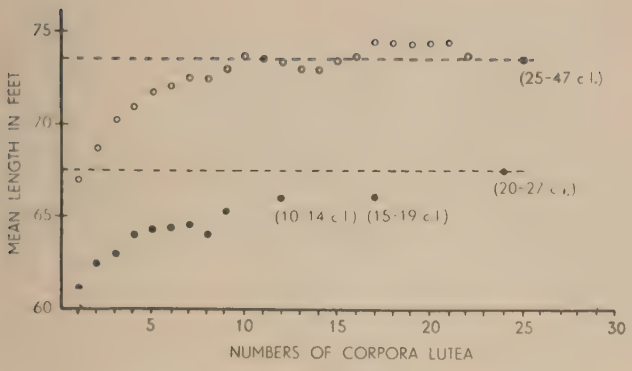


Fig. 3.

Mean lengths of female finbacks in relation to numbers of corpora lutea.

● British Columbia ; ○ Antarctic (Brinkmann, 1948).

1. the age at the attainment of sexual maturity,
2. the frequency of breeding seasons and
3. the number of ovulations per breeding season.

the comparison presented in figure 3 shows that growth is slower in northern finbacks both prior to and following sexual maturity. The relatively small number of old or fully grown whales in the British Columbia data is insufficient to show the average length at the attainment of physical maturity. It appears, however, to be about 68 feet or less. This length is some 6 feet less than the 74 feet average calculated for the southern finbacks.

From a total of 9 physically mature females in the Norwegian data, Jonsgård (1952) estimates the average length at physical maturity to be about 70 feet, but he considers that this average is probably high.

From the foregoing we may conclude with some confidence that the growth of finbacks from the coast of British Columbia corresponds closely to the growth of finbacks from other localities in the northern hemisphere. British Columbia finbacks

attain sexual maturity at approximate average lengths of 60 feet for the females and 58 feet for the males. These averages are similar to those described for other stocks of finbacks in the northern hemisphere, but are approximately 5 feet shorter than the averages for southern finbacks. The average length at physical maturity for female finbacks from British Columbia seems to be about 68 feet or less, as compared to 74 feet for southern finbacks.

Literature cited

Brinkmann, A. jun. 1948. Studies on female fin and blue whales. Hvalrådets Skrifter, nr. 31, Oslo.

Jonsgård, Åge. 1952. On the growth of the fin whale in different waters. Norwegian Whaling Gazette, No. 2, Sandefjord.

Mackintosh, N. A. and J. F. G. Wheeler. 1929. Southern blue and fin whales. Disc. Repts. Vol. 1, Cambridge.

Nishiwaki, M. and T. Oye. 1951. Biological investigations on blue and fin whales caught by the Japanese Antarctic whaling fleets. Sci. Repts. Whales Res. Inst., No. 5, Tokyo.

Omura, H. 1950. Whales in the adjacent waters of Japan. Sci. Repts. Whales Res. Inst., No. 4, Tokyo.

Ruud, J. T. 1945. Further studies on the structure of the baleen plates and their application to age determination. Hvalrådets Skrifter, nr. 29, Oslo.

(*Reprinted from Nature, Vol.* 171, *p.* 847, *May* 9, 1953)

Swarming of *Nereis succinea* (Leuckart) off the East Coast of Canada

In June 1952 the crew of a fisheries patrol boat cruising in Miramichi Bay, New Brunswick, observed what they took for a sand-bar in an unexpected situation. On closer inspection they found that there was no such bar, but that the surface of the sea over a wide area was in a state of violent turmoil ("a sort of boiling") due to the presence of enormous numbers of polychætes. The area covered was some 150 yards in radius and was broken up into several minor patches. The largest one, from which they took a sample of the polychætes, was estimated to be 75 ft. long and 15 ft. wide, and the polychætes seemed to extend to about 2 ft. deep. The tide was low at the time and the depth of the water about 7 ft. The bottom consisted of hard mud. The observation was made on a fine, warm day.

The polychætes involved were the heteronereid forms (both sexes) of *Nereis succinea* (Leuckart). This is the first record of that species from eastern Canadian waters, though it is known from the eastern coast of the United States, usually under the name *Nereis limbata* Ehlers. Ehlers[1] described in detail the male heteronereid of *Nereis acutifolia* Ehlers, which appears to be another synonym of *Nereis succinea* (Leuckart) (cf. Monro[2]). The specimens from Miramichi Bay agree closely with Ehlers's description.

We know of no other case of the swarming of a nereid with such activity and in such concentrated masses as occurred in this instance, and should be glad to hear of any that has been recorded.

The specimens were submitted by the collectors to Mr. R. A. McKenzie, a representative of the Fisheries Research Board of Canada at Chatham, New Brunswick, and were forwarded by him to Dr. A. H. Leim, of the Atlantic Biological Station, St. Andrews, New Brunswick, who, in turn, sent them to us for identification. We are indebted to the former for particulars of the conditions of swarming.

C. Berkeley
E. Berkeley

Pacific Biological Station,
Nanaimo,
British Columbia.
Nov. 15.

[1] Ehlers, E., "Die Polychaeten des magellanischen und chilenischen Strandes", 118 (1901).
[2] Monro, C. C. A. *Proc. Zool. Soc.*, Pt. 1, 42 (1933).

Printed in Great Britain by Fisher, Knight & Co., Ltd., St. Albans.

338

Canada's Fisheries

AND THEIR ATLANTIC SITUATION

by A. G. HUNTSMAN

A. G. HUNTSMAN, B.A. (Tor., 1905), M.B. (Tor., 1907), M.D. (Tor., 1933), F.R.S.C. (Past President) professor of marine biology at the University of Toronto and consulting director of the Fisheries Research Board of Canada has spent his entire professional life in the field of science of which he writes.

•

Reprinted from
THE CANADIAN BANKER
VOLUME 60 NUMBER 2
Spring 1953

Canada's Fisheries

AND THEIR ATLANTIC SITUATION

by A. G. HUNTSMAN

CANADA owns and adjoins vast and varied waters. How much she owns is becoming more important as man rapidly increases his control of nature. How much she owns or will own is uncertain, since some other countries are claiming ocean farther out than the three miles from shore that has been the traditional distance. Owner-

ship of territory is in general vested in those who occupy and defend it. Man cannot properly occupy water, and how far out he may well defend it is indeed questionable.

Since Canada has a surplus of food, she does not fish the waters available to her at all heavily. There is no very good basis for predicting how greatly she could increase her take of fish, since so large a proportion of the take comes from international waters for whose fish various countries compete. There can be no doubt that the present take represents roughly the comparative availability of fish in the various waters and that no considerable bodies of fish that could easily be taken remain unexploited.

It is climate that largely determines the life picture in water as in air. Most fish, like most men, are in the intermediate and variable conditions of the temperate zone with a changing sun, and also in the northern hemisphere near sea level, where land, air and water all come together. The poles and the tropics, the high land and the deep water are poor producers. Canada's fish are mainly in the shallow water of its short Pacific coast and of its Atlantic coast from the U.S. border to the Strait of Belle Isle. There it is that the fertility of bottom waters is constantly brought near the surface, where alone there is light for plant growth, by seasonal overturn of the water, by tidal action and by the circulation resulting from discharge of fresh water by rivers. Thus our big fisheries over banks and in estuaries are produced.

While the general picture is quite clear from the fishery results, we lack knowledge of an infinitude of desirable detail. The great difficulty in accurately calculating numbers of fish in the water delays progress and is only gradually being remedied. Fishing is worth while only where fish are concentrated. The science of the concentrations, which fishermen largely locate by trial, is only beginning. Also the science of fish capture is as yet in its infancy.

Some of the main ideas that have governed thought and action on fisheries have been proving to be wrong. The hatching and planting of young fish, which were at the end of the last century expected to fill our waters with fish, have not done so. Fish culture is successful, however, when applied to small bodies of water such as ponds, which can be kept rather fully under control, as can farms on land, but as yet this does not seem worth while for us for food purposes. That fish can direct their courses over the bottom, except when in rather close relation with it, lacks a foundation of fact. In their migrations, they wander and are carried by current, which works sufficiently well. Data are showing that rarely does it pay to save

the small fish or the breeding fish. It was supposed that the high breeding rate of fish is an adaptation to offset a high death rate. But the truth is that a high breeding rate makes a high death rate inevitable. Accordingly, fishermen nearly always may as well take the fish they can get, since these must die anyway for lack of effective room. The management or regulation of fisheries, based upon the old ideas, will need to be revised.

The claim that we have been wasting our fishery resources lacks proper basis in fact. We have the illusion of dwindling resources because, with rapidly increasing human population, the number of fish per person rapidly decreases. Poorer fishing also comes at times from a drop in abundance of fish in the course of natural fluctuations, whose causes are as yet little understood. There is also the inevitable effect of heavier fishing on accumulated stocks of old large fish in decreasing their abundance and so reducing the average size of the fish caught. None of these things means that natural productivity has been affected. Indeed, heavy fishing of young as well as old fish may give increased production through the food being eaten by the younger fish which make better use of it in growth.

Although our fishery resources are large, they are limited. Any removal of fish depletes the supply until breeding and growth make the loss good. There is overfishing when the fishing effort is greater than the supply warrants. What catch will pay depends upon circumstances. Newfoundland, with few people, lies in the midst of great fisheries and far from large markets. Consequently, it does not pay Newfoundland fishermen to go elsewhere for fish. But it does pay Nova Scotians, New Englanders and even Europeans to go to Newfoundland waters. The fishing there must be quite good to be worth while for anyone, and so those waters are not intensively fished. The Bay of Fundy has very rich fisheries at its mouth and very poor fisheries at its head, owing to the peculiar ways in which the fish and their food are produced and carried. With general economic conditions so much better now than they were in the latter half of the last century, the good fishing at the mouth of the Bay has been developed greatly, but the poor fishing at the head has been largely abandoned for more lucrative employment, just as on land the less productive farms have been abandoned.

Canada produces only about four per cent of the known world production of fish. About half that production is on the coast of Asia, where the very great human population ensures quite thorough use of the food that is available in the sea as well as on the land. About a quarter of the total is on the coast of Europe with not so great a population, but a greater one than on this continent. Gen-

Fishing Fleet In Port

erally speaking, intensive fishing and good use of fish resources go with heavy human populations, which need the fish for food. We are still far from making very full use of our resources.

In 1949, with a total fish production in Canada of 1,959,064,000 pounds, the proportions taken from the various waters were: Atlantic, 67.6 per cent; Pacific, 27.8 per cent, inland or fresh, 4.6 per cent; Arctic, 0. In 1950, with 2,122,287,000 pounds the proportions were: Atlantic, 65.6 per cent; Pacific, 30.1 per cent; inland or fresh, 4.3 per cent; Arctic, 0. Newfoundland, which entered into Confederation recently, contributed 32.6 per cent of the total in 1949 and 29.7 per cent in 1950. The fisheries of the Atlantic coast, particularly those of Newfoundland, are related to extensive fishing banks out in the ocean. In contrast, the shorter Pacific coast of British Columbia lacks extensive banks, but with strong estuarial action from heavy discharge of rivers that drain the rainy, western slopes of the coastal and Rocky mountains, has a high production.

No figures are available for the proportions by weight of the fish that are exported or imported. Nor is it known what are the contributions of the various provinces to the exports. The situation is complex and neither easily determined nor properly appreciated. As the fish are processed, the weights change. On the way from the

water to the consumer, the value of the fish steadily mounts. Landed weights and values are basic, but are not available for exports and imports. However, marketed values of Canada's production of fish in 1949 and 1950 have been given as $165,306,000 and $182,003,000 respectively. The values of the fish exported were $105,200,000 and $118,555,000. The values of the fish imported were $6,397,800 and $5,142,700. As far as can be judged from these figures Canada consumes only about 40 per cent as much fish as she produces. With changing tariffs and international difficulties in currency exchange, the export market is a precarious one. The fisheries, therefore, with such great dependence upon export, are not in a very favourable position.

In the eastern end of habitable Canada, the North American continent juts markedly out into the Atlantic Ocean in the form of the great island of Newfoundland. Below water, it juts much farther out as the Grand Bank. This feature combines with the rotation of the earth to give our Atlantic waters most diversified fishery conditions. Off the tip of the Grand Bank, where the *Titanic* sank, is staged the most striking part of the continuous dramatic struggle between cold from the Arctic and heat from the tropics. Thither come both the coastal Labrador Current, sometimes spectacularly laden with enormous icebergs from Greenland, and also the offshore Gulf Stream, that has its surface strewn with floating seaweed, doubtless from the Sargasso ocean near the equator. Inside the main battleground that is over great ocean depths, the rival forces commingle over banks, around islands and in bays, while the discharge of rivers, of which the St. Lawrence is chief, and the great temperature changes of the continent add their contributions to the complex picture.

The land is affected. Incipient glaciers at sea level may be seen on the Labrador coast at the Strait of Belle Isle, to which point the treeless Arctic tundra and the Eskimo perilously extend their domain from the north. In southern Nova Scotia, peaches and grapes, together with the negro, have been introduced, but survive with difficulty. In the sea, the comparatively barren conditions of the Arctic with little alteration extend south along the coast to the Strait of Belle Isle. They are recognizable while being steadily ameliorated along the courses taken by the water on the outer coast of Newfoundland and on the north shore of the Gulf. Colonies of the northern walrus were formerly to be found on Sable Island off the coast of Nova Scotia and at various places in the Gulf and River of St. Lawrence. A large colony of the white whale or beluga lives in the St. Lawrence estuary at the mouth of the Saguenay River, and capelin are abundant in the northern part of the Gulf. Both

The catch is stowed on a fishing trawler on the Grand Banks.

Placing Cod on fish flakes to dry at Bonavista, Newfoundland.

of these are occasionally in the Bay of Fundy. Lobsters and cunners that need warm water are almost excluded from that Bay as well as from the north shore of the Gulf, but, curiously enough, they are very abundant adjacent to the inner end of the Strait of Belle Isle, in the warm shallow bays of the northern part of the west coast of Newfoundland. Oysters, which are proper to Florida, have as their only home north of Cape Cod the warm (in summer) estuaries around Prince Edward Island in the shallow southern part of the Gulf. On the other hand, like the floating ice, enormous herds of Greenland seals and smaller numbers of hooded seals come south every year in the cold weather, not only in the Labrador Current to the outer coast of Newfoundland, but also through the Strait of Belle Isle and along the north shore to the centre of the Gulf, even at times reaching the St. Lawrence estuary.

A high standard in the collection of fisheries statistics was set by Dr. Pierre Fortin, who was responsible for administration of the fisheries on the Gulf shores of Lower Canada (Quebec) under the Province of Canada from 1855 to 1867. With Confederation his system was extended to all the provinces. Newfoundland is only now adopting the system that was developed from the start he made. In Newfoundland, fish means codfish. Cod-fishery made Newfoundland Great Britain's first colony, the wealth of cod on the adjacent banks making it a most desirable base from which to prosecute the fishery. That became the role that Newfoundland has played for several centuries. Its other possibilities have only slowly been coming to realization. Full statistics on its present situation are not yet available on the same basis as for the other provinces.

Cod are to be caught over the banks and all around Newfoundland, and also in diminishing numbers along the Labrador coast of the mainland to the north, which belongs to Newfoundland, as far as Hudson Strait. Cod still provide the bulk of the Newfoundland catch, forming, with small quantities of related kinds, over 70 per cent of the 1950 catch. Most of the cod are salted and dried for export, going for the year ending in June 1951 to 35 different countries, the principal amounts in quintals being: Puerto Rico, 209,414; Portugal, 208,863; Italy, 151,102; Jamaica, 106,849; Brazil, 52,838; Barbados, 26,860; Yugoslavia, 19,926; Cuba, 19,889; Greece, 11,634; Dominican Republic 10,728. It is an important question whether Newfoundlanders can make a proper living by producing dried fish from the wealth of cod near their shores, but largely in international waters, seeing that these can be sold only as a cheap food for the people of poor countries in warm regions, that have but small local supplies of fish, even when surrounded by water.

Newfoundland, however, has had substantial fisheries for herring, salmon, lobsters and clams. In recent years, she has been trying to escape from dependence upon the dried fish trade by developing other and more lucrative markets for her fish, particularly those of this continent which demand fresh fish for the most part. In doing this, she has greatly diversified her fisheries. The quantities in thousands of pounds landed in 1950 of the various main kinds, but including for each the related kinds, were as follows, according to information prepared for FAO: Cod, 452,111; herring, 70,563; salmon and capelin, 54,981; rosefish, 23,726; halibut, 15,318; clams, 5,591; lobsters, 5,051; tuna and mackerel, 3,362; wolffish or catfish, 359. Newfoundland is most advantageously situated for very great fisheries. These will come with development of the most effective techniques for capturing the fish and for preparing them most suitably for whatever markets there may be available.

The Maritime Provinces have most varied fisheries. Prince Edward Island is entirely, and Nova Scotia almost, surrounded by water, so that only New Brunswick is so far in the continent as to have any considerable quantities of strictly freshwater fish, with merely $2,800 worth of pickerel and $1,100 of suckers in 1950. Nova Scotia is farthest out in the ocean and provides more of such bank or deep-sea bottom fish as cod, haddock, hake and halibut, and of such open-sea surface or mid-water fish as mackerel, tuna, swordfish and rosefish. New Brunswick leads in estuarial or river migratory kinds, such as gaspereaux or alewives, smelts, tomcod, shad, salmon, oysters, striped bass and clams. The smelt fishery of the Miramichi estuary is outstanding in the world. The fishery for young herring to be canned as sardines in the Passamaquoddy region of southern New Brunswick is without a peer anywhere. The very great variety, which will doubtless be greater in the future, appears in the following list of landed values in thousands of dollars for the Maritimes fisheries in 1950: Lobsters: 11,634, Cod: 6,070, Halibut: 2,638, Haddock: 2,366, Herring: 2,200, Smelt: 806, Mackerel: 784, Swordfish: 719, Soft-shelled clam: 543, Salmon: 514, Pollock: 409, Hake: 390, Oyster: 348, Scallop: 345, Plaice: 251, Alewife: 164, Irish moss: 123, Flounder: 107, Shad: 80, Tuna: 60, Rosefish: 57, Yellowtail or dab: 52, Catfish or wolffish: 43, Cusk: 21, Witch: 18, Tomcod: 15, Dulse: 14, Squid: 12, Quahaug: 12, Various: 7.9, Bar clam: 4.5, Striped bass: 4.3, Pickerel: 2.8, Periwinkle: 1.6, Skate: 1.4, Kelp: 1.4, Sturgeon: 1.2, Seaweed: 1.2, Sucker: 1.1, Crab: 1.0, Silverside: 0.6, Seal: 0.5.

The international situation in the Atlantic is best shown by the figures for groundfish taken by various countries off the coast of

North America from New England to west Greenland, as reported by the International Commission for the Northwest Atlantic Fisheries. The craft used by fishermen from Europe are dory vessels, otter trawlers, pair trawlers and long liners. The amounts in thousands of pounds taken off the various parts of the coast in 1951 were as follows: New England: 440,653, Maritimes: 613,954, Newfoundland: 748,488, Labrador: 64,930, West Greenland: 375,766. In addition there were 534,124 thousands of pounds not definitely referable to the above sections of the coast, but mainly referable to the Newfoundland section. The countries fishing off each part of the coast were: *New England*: United States. *Maritimes*: Canada and United States. *Newfoundland*: Canada, France, Portugal, Spain, Italy, United States and Great Britain. *Labrador*: Canada, France, Portugal, Spain and Great Britain. *West Greenland*: Denmark, France, Portugal, Iceland, Norway and Great Britain. The predominant position of the Newfoundland area is evident.

The fertility of the ocean which covers almost three quarters of the earth is inexhaustible. We are fortunate in having it produce continuously, by circulation of water to our shores, such great quantities of fish and other organisms for our use.

A SEAWATER SAMPLING BOTTLE[1]

By

R. L. I. FJARLIE

Pacific Oceanographic Group,
Nanaimo, B. C.

ABSTRACT

new type seawater sampling bottle consisting of a tube with hinged lids and a
ne holding three reversing thermometers is described. The bottle is designed to
ree flushing, reliable mechanically, and simple to operate. The relative sampling
iency of Nansen, Knudsen, Ekman and new type bottles is compared.

The earliest seawater sampling bottles, such as those used on the
t CHALLENGER Expedition, consisted of a simple tube through
ich the water flowed more or less freely (flushed) while it was
ered on a sounding line to any desired depth. When in position,
was closed by striking a trigger mechanism with a small weight
essenger) which slid down the line. With the advent of reversing
rmometers in 1902, a reversing mechanism was added.

The most successful bottles are the Nansen (Wüst, 1932), Knudsen
nudsen, 1929) and Ekman (Knudsen, 1923), in which the ther-
meters are attached to the tube which reverses and closes when the
gger is actuated. In the first two, both ends of the bottles are
ached to the sounding line while they are lowered into position;
en the messenger strikes the releasing mechanism, the top end falls
ay from the line by its own weight and reverses. There is a common
jection to them in that the sampling tube is not perfectly sealed
en the bottle is reversed. Because their flushing characteristics
poor they must be left at the sampling depth for some time to
tain a true sample.

In the Ekman bottle the thermometer and sampling tube assembly
mounted on pivots in a frame that can be attached to the sounding
re at both ends. It has relatively good flushing characteristics,
d with care the lids on the tube can be maintained leak-proof.
t this bottle, though rugged, is very heavy and tiresome to use.

The ideal water sampler must obtain and preserve a true sample of
water at the sampling depth and bring it on shipboard intact.
is requires good flushing characteristics when open and a positive

[1] Plans and specifications may be obtained at cost from the Oceanographer in
rge, Pacific Oceanographic Group, Nanaimo, B. C.

rint from *SEARS FOUND. JOURN MAR. RES.*

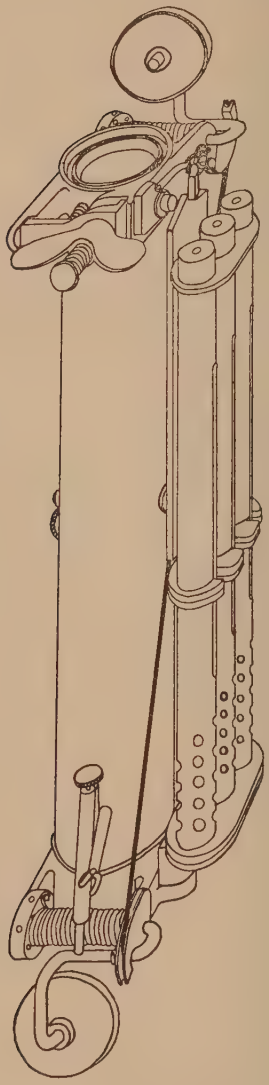


Figure 1. The seawater sampling bottle.

when closed. Furthermore, once the thermometers have reversed should be locked in position to safeguard the temperature read-. The unit should be fastened to the line at both ends to prevent age against the side of the ship in rough weather, and the ther-neter cases should be readily removable so that these instruments be stored properly (Ekman, 1905; Richter, 1950) between ob-ations at sea.

THE NEW SEAWATER SAMPLING BOTTLE

With the requirements of an ideal water sampler in view, a new le has been designed (Fig. 1) to incorporate as many of these ures as possible. The design was commenced in 1949 and the otype of the present bottle was first used in January 1950. Since the design has been modified six times. It is presented here as a which has proved dependable, easy to handle, and capable of aining true samples and temperatures.

his sampling bottle consists of a light metal tube with hinged lids ach end which are co-ordinated with a rotating frame that holds e reversing thermometers. The tube is clamped to the sounding at the top and is hooked at the bottom end, similar to the Ekman le. A device below the bottle for releasing a messenger when it es allows any number of units to be used in series on the line. The or features which have been designed into the bottle permit unre-ted flow of water through it when open, a positive seal when the are closed, and complete mechanical reliability.

he free flow of water through the bottle has been facilitated by nting the operating springs outside on the lid hinges and by pro-ng large openings at the ends of the tube. The only impediment ow is a ¼ inch diameter axle which passes transversely through the er of the tube to support the reversing thermometer frame.

he tube is sealed by flexibly mounted lids which carry a rubber ket (Fig. 2). The flexibility of the mount allows the lid to adapt f to the end of the bottle in case the hinge bar becomes bent in ice, and the metal rim which forms the seal with the gasket has slightly recessed inside the bottle to prevent damage.

flexible cable forms the link between the lids and the reversing momometer frame so that when the frame is rotated it also opens lids against the springs. A lock is provided to prevent accidental ning with consequent loss or contamination of the sample and rs in the thermometer readings. A removable case holding three momometers locks to the reversing frame with two spring catches.

he bottle has an eye welded to the tube at each end so that it can ung upright on a hook before the thermometers are read and up-

side down after the sample is drawn and temperatures are recorded. In this way the reversing thermometers can be kept in the approved storage position (Richter, 1950) while they are still on the bottles if it is not convenient to transfer them to a separate rack. In practice, a wooden case fitted with hooks serves as a bottle rack on deck and as a case for shipping.

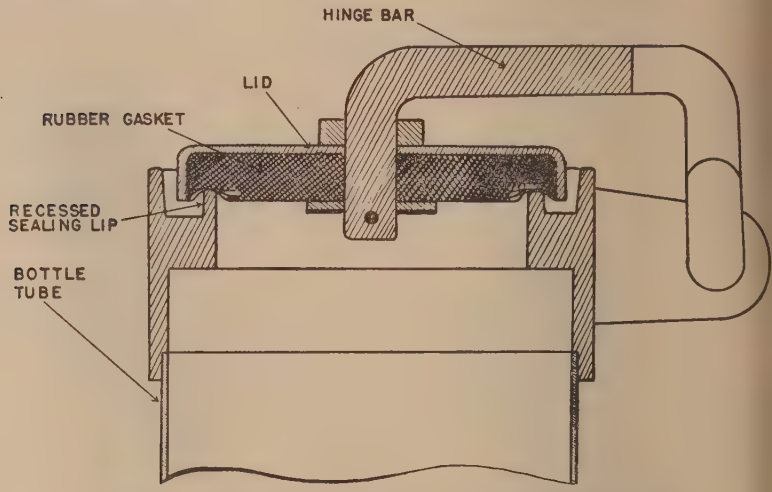


Figure 2. Detail of lid construction on the seawater sampling bottle.

The weight of the new bottle (7.3 lbs.) compares favorably with that of the Nansen bottle (7.7 lbs.) and its weight is the same as that of the Knudsen bottle. It is much lighter than the 17-pound Ekman bottle.

The messenger, a "split" type, is cast in two pieces of manganese bronze which are held together under tension by a heavy piece of rubber. The messenger is pushed onto the line and pulled off, but it has no tendency to fall off or to become jammed.

In use, the bottle is first attached to the sounding line by a spiral hook at the lower end (Fig. 3A) and then clamped at the top (Fig. 3B). The plunger which locks the thermometer frame is released and the lids are opened by rotating the frame 180 degrees until it engages the trigger (Fig. 3C). The messenger is then attached to a spring loaded plunger that bears against the lower hinge bar (Fig. 3D), and finally the messenger is fitted to the line.

Every attempt has been made to reduce the number of motions required. The hook at the lower end is positioned so that the movements used in attaching and detaching the bottle from the line are

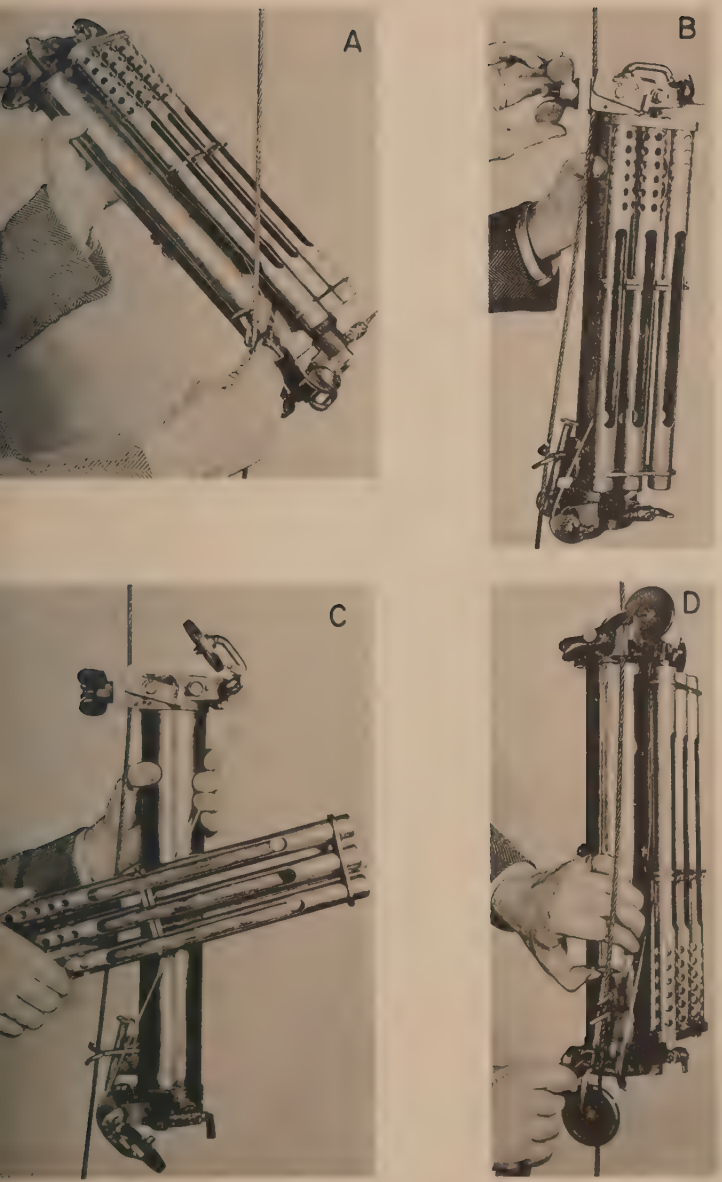


Figure 3. Attaching the bottle to the sounding line.

those which would naturally be used in moving the bottle to or from the wire. The bottle is designed so that it can be held in the left hand while the right hand performs the more complicated motion of screwing up the clamp, which has a large wing nut to attach it securely to the line with reasonable effort. Both lids are opened and the thermometers are reversed in a single motion. The messenger is attached after this action is completed so that the operator does not have to coordinate two moving parts.

FLUSHING EFFICIENCY—A COMPARISON WITH OTHER SEAWATER SAMPLING DEVICES

In a single experiment the relative efficiency of the Nansen, Knudsen Ekman and Fjarlie bottles was investigated in water having a moderate salinity gradient. Strings consisting of four bottles of each type attached at two-meter intervals, were hung side by side from a bar suspended from the main cargo boom of H. M. C. S. Cedarwood, the end of which was high enough above the sea to allow all of the bottles to be in the air at once. With bottles open and messengers attached the four strings were lowered into the water, and at a measured time from immersion of the uppermost bottle, messengers were dropped on each line simultaneously. The bottles were then hauled up and the samples were drawn. This procedure was repeated to obtain samples after a submersion time of 0, ½, 1, 1½, 2, 3, 4, 5, 6, 9, 11 and 15 minutes, the different intervals being observed in random order (Table I).

It is believed that this method of sampling makes it possible to estimate the time required for a bottle to flush completely by comparing the salinity of the samples taken. Ideally, the time required for complete flushing of all bottles is the time from which they are submerged until all bottles at the same depth have identical samples. In this experiment an arbitrary reference salinity for each cast was obtained by choosing the maximum salinity at each depth, regardless of the type of bottle from which it was drawn. If the salinity as shown by one bottle was less than the reference salinity at the same depth, it was assumed that some water of a lower salinity had been trapped in the bottle and had been carried down with it to the sampling position.

To evaluate the relative efficiency of the different bottles, the area between the reference salinity curve and the curve shown by each type of bottle was measured for the various submersion times. It was assumed that, as this area approached zero with longer "soaking," flushing became more complete. Thus, the efficiency is measured by

BLE I. The Salinity (‰) of Samples Taken Simultaneously in Four Types of Sea Sampling Bottles After Various Intervals of Immersion

oth i)	*Type of Bottles*			
	Fjarlie	*Nansen*	*Knudsen*	*Ekman*
		0 Minutes Immersion		
	23.35	23.39	23.33	23.31
	23.42	23.33	23.35	23.37
	24.43	23.57	23.64	24.30
	—	24.69	24.78	25.48
		½ Minute Immersion		
	23.93	23.90	23.93	23.90
	24.16	24.00	23.90	23.95
	—	24.36	24.42	24.78
	25.62	24.90	25.55	25.64
		1 Minute Immersion		
	24.40	24.27	24.29	24.29
	24.29	24.30	24.30	24.29
	25.30	24.74	25.01	25.28
	25.68	24.69	25.52	25.68
		1½ Minutes Immersion		
	23.98	24.50	23.98	24.02
	24.20	24.14	24.16	24.16
	24.81	24.61	24.69	24.81
	25.81	25.52	25.73	25.80
		2 Minutes Immersion		
	24.36	24.38	24.40	24.40
	24.51	24.45	23.87	24.47
	25.35	25.16	25.39	25.41
	25.59	25.50	25.59	25.57
		3 Minutes Immersion		
	24.02	24.00	24.02	24.00
	24.00	24.04	24.00	24.04
	24.92	24.61	24.92	24.94
	25.75	25.53	25.73	25.72
		4 Minutes Immersion		
	23.60	23.69	23.71	23.69
	23.73	23.71	23.73	23.74
	24.34	24.05	24.18	24.34
	25.59	25.48	25.57	25.57

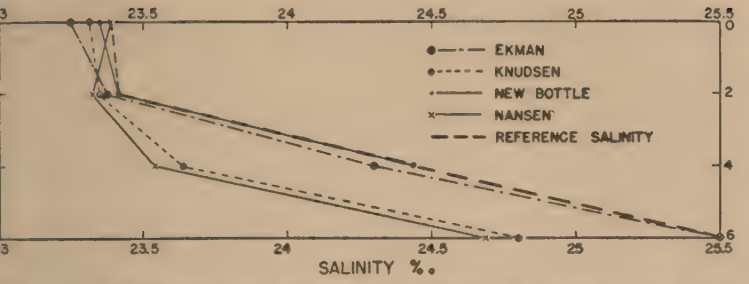
the area between the curves and the time required for them to approach zero. For discussion purposes, the units of area have been called "Salinity Meters" (S. M.).

The data are shown in Table I. The salinity profiles for a submersion time of 0 minutes are shown in Fig. 4, together with the reference profile.

TABLE I.—Continued

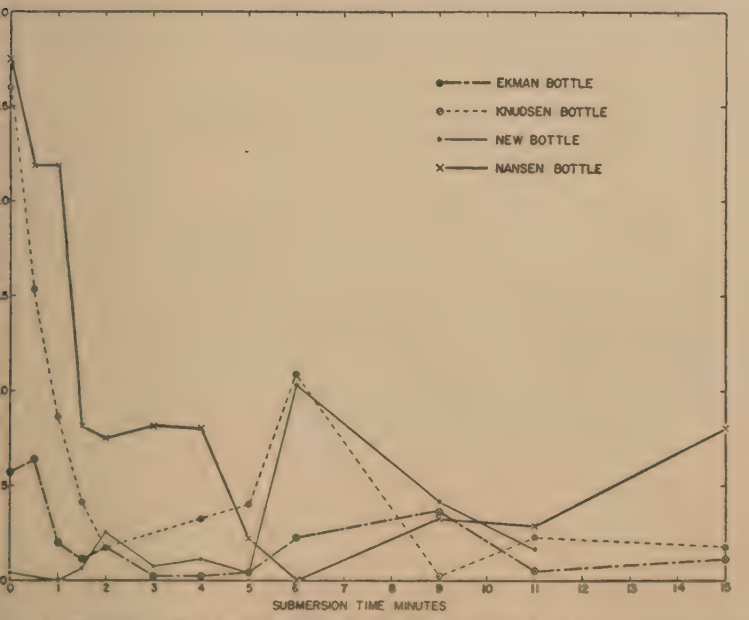
Depth (m)	*Type of Bottles*			
	Fjarlie	*Nansen*	*Knudsen*	*Ekman*
		5 Minutes Immersion		
0	24.14	24.13	24.11	24.05
2	24.11	24.13	24.11	24.14
4	24.47	24.38	24.31	24.47
6	25.73	25.64	25.72	25.72
		6 Minutes Immersion		
0	24.11	24.18	24.11	24.11
2	24.22	—	24.27	24.27
4	24.76	25.16	24.69	25.10
6	25.82	25.84	25.82	25.84
		9 Minutes Immersion		
0	23.59	23.66	23.62	23.57
2	23.69	23.62	23.71	23.68
4	24.45	24.54	24.61	24.50
6	25.55	25.61	25.62	25.62
		11 Minutes Immersion		
0	24.18	24.07	24.11	24.11
2	24.22	24.25	24.27	24.27
4	24.58	24.54	24.52	24.60
6	25.81	—	25.81	25.80
		15 Minutes Immersion		
0	23.48	23.44	23.38	23.44
2	23.48	23.51	23.50	23.55
4	24.09	25.10	25.37	25.39
6	—	25.64	25.72	25.62

The relative efficiency of the four types of bottles is shown in Fig. 5. The variation in the data, about 0.25 S. M., becomes approximately constant after nine minutes submersion time. The data for the six and 15 minute intervals are not consistent with the remainder of the series and cannot be explained from the records of the experiment.



gure 4. The salinity of samples taken simultaneously in the four types of bottles after minutes submersion.

spite these anomalies, the relative efficiencies are clearly indicated. these waters, where the salinity (and consequently the density) dient was moderate, the samples in the new bottle apparently were equilibrium with the surrounding waters immediately, those taken he Ekman bottle after one-half minute, the Knudsen samples after minutes, the Nansen bottle samples after five minutes "soaking."



ure 5. Deviation of the salinity in each type of sample bottle from the reference value. ency varies inversely with the deviation.

When a bottle is being lowered, flushing results from the velocit head in the fluid at the end opening; after the bottle is in position th lighter water, entrapped and carried down in the lowering, will floa out and be replaced by the denser surrounding water. During th lowering, when the velocity is greatest, small end-openings an internal obstructions cause a flow resistance which is most effective i retarding the flushing, but it is also effective in retarding the hydro static flushing when the bottle is in position.

The data in Fig. 5 show that the efficiency is proportional to th effective size of the end-openings and to freedom of flow through th bottles. While the end caps on the Ekman bottles undoubtedl retard free flow, equilibrium is quickly attained (½ minute) becaus of the large openings and an unobstructed tube. The end-openin of the Knudsen bottle is of fair size, but it is partially obstructed b the internal spring, which also occupies a large percentage of the cros section area in the narrow bottle. The stopcocks on the Nanse bottle constrict the end-openings so much that flushing requires mor than twice the time of any other bottle.

The bottle described here approaches the postulated requirement more closely than any of the bottles designed previously, and it i believed to be an acceptable improvement.

REFERENCES

Ekman, V. W.

1905. On the use of insulated water bottles and reversing thermometers. Pub Circ. Cons. Explor. Mer., *23:* 27–28.

Knudsen, M.

1923. Some oceanographical instruments. Publ. Circ. Cons. Explor. Mer., 77 9–10.

1929. A frameless reversing water bottle. J. Cons. int. Explor. Mer., *4* (2): 19

Richter, N.

1950. Über die Funktion der Umkippthermometer sowie die Beseitigung vo storungen. Richter and Wiese, Berlin. 9 pp.

Wüst, Georg

1932. III. Die bei den serienmessungen angewandten methoden und apparat 1. Wasserschöpfer, thermometernahmen. Wiss. Ergebn. dtsch. Atlan Exped. Meteor, 1925–27, *4* (A): 21–30.

RESEARCH IN SALMON MIGRATION OVER HIGH DAMS
THE NATURE OF THE BIOLOGICAL PROBLEM

J. R. Brett
Biologist, Pacific Biological Station, Nanaimo

INTRODUCTION

For salmon, the biological problem resulting from the creation of high dams hinges largely on one chief characteristic—that of migrating. With the exception of a small fresh-water form of sockeye called kokanee, the five species of west coast salmon all migrate seaward as young fish and return to fresh-water spawning grounds as maturing adults. This cycle of events cannot be broken and still hope to maintain the survival of these stocks of fish. Consequently, it is the nature of *migrating salmon,* their particular responses and capabilities, which constitutes the biological problem.

While it is possible to conduct profitable studies on the dissecting table, or in the laboratory tank, the fish is no longer in its natural environment, and the normal functioning of its system can only find full expression as a function of its natural environment. Migration is the resultant of behaviour in a particular environment. To take an example from adult salmon, once the fish reaches the spawning grounds it no longer migrates but proceeds with a new behaviour—building an egg "nest." Emphasis must be placed, therefore, on the fact that the salmon reaching the dam are active, perceiving, sensitive fish, moving with surprising precision and persistence. Lack of knowledge of the behaviour and sensitivity of such salmon is one of the main handicaps to solving the problems created by high dams.

It is useless to search biological literature for the answer, though much of the background and methods of study will be found there. The fish have not been examined sufficiently under conditions imposed by large reservoirs, submerged outlets, rapid fluctuations in flow, and catastrophic pressure changes, to provide answers. Nor is there any good knowledge of the physical conditions which the fish actually face. No excuses are necessary for this lack of knowledge. The changed water conditions are a product of our times. Solutions to the problems created are the task of our times.

The case for downstream migrants will be considered here. Not that it is any more important than that for the upstream migrants, but, to date, less is and can be done to alleviate the mortalities among the young fish which result from high dams.

The necessity of developing adequate conservation measures is based on the premise that losses actually do occur when young salmon pass either over a high spillway or through a high-pressure turbine. This subject has been considered in an accompanying paper. It can be stated that unequivocal evidence of serious losses has been obtained. The need for conservation is real and pressing. How, then, should biological research be formulated?

Reprinted from the Sixth British Columbia Natural Resources Conference Transactions, 1953.

Background Knowledge Required

In the Babine River, tributary to the Skeena River, the production of yearling sockeye migrants for an average year can be calculated at about 5,000,000 [1], with a probable present maximum of 15,000,000. How to permit these fish to continue their downstream progress without appreciable loss, if a high dam were constructed in this river, is an example of the type of problem to be faced. To answer this, two paths of research must be developed. The urgency is such that both the biological foundation and a superstructure of remedial action must be built simultaneously. Without the foundation of basic biological understanding, the superstructure of an informed "try this, try that" may well collapse. With insight and good fortune it may support itself.

To conduct experiments of an immediate nature, relative to safeguarding downstream migrants, the Fisheries Research Board carried out experiments on deflecting young spring salmon during the spring of 1952. It was proposed to use a submarine "wall" of air bubbles which could be illuminated by flashing or continuous beams of light, and to test this technique in a small stream (Brett and MacKinnon, 1952). Despite the fact that little is known of either the visual responses in young salmon, their ability to detect sounds, or their migratory behaviour patterns, this "superstructure" approach appeared to have possibilities. It proved to be sufficiently effective to warrant more extensive investigation. In addition, basic research on sight in young salmon is now a part of the research program at the Pacific Biological Station. Thus, both applied and fundamental experiments are being conducted.

These findings, as they develop, must be weighed in the light of the actual conditions in a major river like the Fraser, and tested above existing high dams. The design of effective experiments depends to a large extent on an adequate knowledge of where the migrants are, and how they are behaving in the approaches and immediate vicinity of the dam. At present it is virtually impossible to answer such questions as:

Are the fish actively swimming, or passively swept downstream?
Are they in schools, or individually dispersed?
Is the daily migration continuous, or fluctuating?
Are they near the surface, or deep down? [2]
Are they inshore, offshore, or scattered? [2]

These questions will apply to each of the five species of Pacific salmon, the pink and chum salmon which migrate as fry, the spring and coho salmon which tend to move more gradually downstream over a period of six months to a year, and the sockeye, which usually migrate as yearlings or two-year-olds. The possible number of answers to the above questions of timing and distribution for each of the five species results in a startling array of combinations. Thus, in one and the same environment pink fry could be swept downstream, throughout the day, dispersed in relation to both depth and shore, while sockeye yearlings were swimming downstream

(1) Estimates made from the recapture of marked migrants released in the Babine River, 1952.

(2) Some information is available for spring salmon in the forebay of Bonneville dam, above the powerhouse only (Burner, 1949). In this instance considerable scattering appeared to exist, with a peak of concentration at depths of 40 to 50 feet.

schools, near the surface and close to either bank, the majority arriving above the dam during night and early morning hours. The number of possible combinations of these alternative categories approaches five hundred. Obviously this cannot be the case in actuality; but which are the prevailing combinations for any one species? If it could be established that the statement just made for sockeye applied to 80% of the migrants of this species, the corner stones for appropriate research would be solidly in place.

Directing Downstream Migrants

While we may hope that the engineer with his usual ingenuity will devise some scheme to "pluck" the migrants safely from in front of the dam, this thought must be purely a passing one to the biologist. Although appreciating the points of view, and working in the fullest co-operation with the engineer, the biologist must not be distracted from his own field of inquiry. It should be repeated that the biologist is working with all the complexities of a living creature, not wholly unpredictable in behaviour, but far from a mechanical horse. It is perhaps self-evident that the last point in downstream migration where the young salmon can still be handled is the immediate vicinity of the dam. It is perhaps *not* so evident that, biologically, this is possibly the last place to consider. This particular location is one of confusion to an animal conditioned to natural circumstances. Few lakes have submerged outlets together with backed-up or free-flowing surfaces. The reservoir is a hybrid between lake and stream; its characteristics are neither completely of one nor the other, and its geological history is but momentary, created almost within the span of one fish generation. The expedient move is to examine the "above-dam" area for a locus which provides the greatest normality with regard to natural relations of flow and temperature, in keeping with the past history of the species.

Almost all sockeye spend the first year of their life in a lake. From this medium of relatively stationary water they quite suddenly appear in the spring of the following year, congregated near the surface and moving consistently towards, and with, the accelerating waters of the outlet. Two responses are invariably displayed—coming to or near the surface, and moving into rapid waters. How this is achieved, or what these young fish are both perceiving and responding to, are unknowns. Various theories exist. The basic observations are consistent. In addition this migration, for sockeye, is a mass exodus. At Cultus Lake on the Fraser it is reported that 80% of the total annual migration occurs within a two-week period (Foerster, 1937). Essentially the same timing was discovered at Lakelse Lake, tributary to the Skeena River (Brett and McConnell, 1950). This period represents about 1/25 of the total free-swimming life of the fish to that age. It would be difficult to support a theory of migration based on random behaviour in the face of such facts.

It is not in any way foreign for sockeye to pass through a series of lakes in their seaward movement. Morrison Lake on the Skeena supports an average run of 5,700 adult sockeye (Brett, 1950). The progeny from these spawners, after a year in Morrison Lake, move downstream into Babine Lake, where a minimum distance of 40 miles separates them from its outlet. They must pass through this lake, in company with the much

greater numbers of Babine yearlings, down the Babine River and into a third lake, Nilkitkwa Lake, thence into the continuing and outlet Babine River again. In each instance they must approach the surface; in each instance they must congregate to pass into relatively constricted but faster-moving outlet waters. This is the normal experience of the fish. How can this sequence be repeated in the reservoir areas in such a way as to collect the migrants *prior* to their being influenced by strong flows in the vicinity of the dam? The logical point of operation is the first area above the dam which can be demonstrated by hydrographic survey to be free from the conflicting turbulence of the "near dam" water. Biological thinking can therefore be translated away from the dam and focussed on the drifting waters some ten, possibly fifteen miles upstream, where a long reservoir is created. This has striking resemblances, superficial as they may be, to the shores of Babine Lake, ten to fifteen miles above its outlet. Are the fish in the same relative positions in these two environments? At present there is no answer; but there is reason to believe they might be—the conditions are more natural.

Having reached this point of reasoning, one more decision can be added. In order to manipulate these tons of small fish into a position where they can be handled, they must be *directed* somehow across the moving front of water, also headed seaward. Biologically this is "against the grain." To stay "with the grain" yet achieve the ends must be the aim. To speculate, it would seem that the answer lies in a form of deception. Instead of directing the migrants out of the flow, direction *into* the flow is required. And by into the flow is meant into accelerating water. By using a wide-angle deflecting technique, in the form of a large upstream "V" (of light, sound, air bubbles, electric discharge—whatever can be found to work), the multitude must be gradually eased shoreward into mechanically stepped-up water flows, "dragging" them and water into tunnels or conduits destined to discharge below the dam. Attracting water and transporting water are involved. The volumes required for each are vastly different. The former is, once again, among the unknowns. Laboratory experiments and calculations can be made to determine the latter. If another salmonoid, the speckled trout, can be taken as representative of the oxygen demands of a sockeye of equal weight, then the 5,000,000 (possibly 15,000,000) yearlings of previous reference, arriving at the rate of as many as 500,000 per day, would require less than one cu. ft. per sec. of water to supply them with adequate oxygen for transportation in a closed system for two hours (see Shepard, 1953). For industrial purposes the excess water used for attracting could be progressively filtered from, say, the tunnel for further work through the turbines.

The most pertinent biological question still remains. How to direct the migrants?

The term "directing" is a general one. It consists of at least four, more specific, components when applied to directing fish, namely, *attracting, guiding, scaring,* and *inducing* (the latter used to imply forced swimming, in which the fish have no "free" choice). Each of these can be examined as to meaning, significance, and prospects for application in the present problem.

Attracting. Any environmental influence which brings about a positive response in the direction of that influence can be termed "attracting." Thus, the release of an odor by a female is an influence attracting the male. Factors related to feeding, reproducing, and increased scope for activity (optimum temperature, pressure, etc.) would be attracting. Migration appears to be a general behaviour which has evolved relative to the survival of the species as a whole rather than the individual. It is inconceivable that young sockeye should be able to perceive better feeding grounds in the ocean from some upstream point. Instead, positive responses resulting in migration are made in relation to particular features of the environment. It can be said that these key points of the environment become "attractive" to young sockeye, usually in the spring of their second year. "Migration" is merely a description of the result. During migration the fish must feed. Some stomachs are found to be full of small larval insects. Odors, movements, or shapes depicting food would be attractive. However, the one all-pervading attraction at this stage appears to be directly related to moving, or accelerating, water. Whatever applied means of directing young salmon are practised, it would seem logical, even necessary, to make use of moving water as an attracting factor.

Guiding. Guiding does not involve any physical attraction or repulsion, it merely signifies a series of neutral reference points. Fish moving along the wing of a net are probably guided by sight, or detection of compression waves off the obstruction by sensitive nerve endings in the skin (lateral line). They do not make direct tactile contact unless the object has not been previously perceived or they have been swept onto the net. The use of a "wall" of air bubbles to direct migrating young spring salmon was conceived as a guiding factor. (To the fish it may have fallen partly or entirely in some other category.)

For a schooling fish perhaps more than a dispersed fish, guiding is a directional method of good potential application, because of their tendency to stick together.

Scaring. Above all else, individual survival appears to take immediate precedence over prolonged survival of the race. It seems possible to hold up a migration for a time by threatening the individual life, but only for a time. Predators have been observed to scare a school of migrating fish away from an outlet stream. This is an immediate but limited response. Factors menacing survival (predators, extremes of temperature, warning odors, etc.) constitute scaring agents. The use of these when experienced by the fish for quite limited periods also shows promise. Continuous application would seem most appropriate when migrants are scared into a zone of attraction and carried off by water of accelerating speed (though diminishing volume) which exceeded their ability to return upstream.

Inducing. It has been discovered that certain electrical impulses induce a fish to make body movements which direct it toward one pole in an electric field (Groody et al., 1952). "Forced swimming" is a convenient description of the response. It is little understood and poses challenging fields of investigation. Its novelty and laboratory success have caused optimism beyond sound judgment from present factual information. It may be cautioned that its application in moving waters can cause the fish

to orientate broadside to the stream. This is an impossible situation where no precaution has been taken to counteract downstream displacement. The previous directing factors did not involve cross-stream orientation of fish. Nevertheless, "induced" directing provides as much potential for successful use as any other directing factor to date.

Conditioned Directing. With the exception of forced swimming the directing factors considered have relied on the normal or innate behaviour of the fish. If this is found unprofitable an alternative approach is suggested through the method of conditioned reflexes. By exposing downstream migrants to a series of shocks or other punishment, always associated with some readily perceived stimulus (e.g. flashing light, beamed sound) more effective techniques might be brought into practice. The rapidity with which young sockeye might learn to avoid new aspects of their environment is a question for future experimentation. By exposing them to a series of distressing experiences at intervals of, say, ten miles along the path of migration, a considerable number of exposures could be introduced.

In General

It is hoped that some clarity to the high dam problem has been achieved by examining it purely biologically. It will be more than clear that knowledge of the fish and the environment concerned is sparse.

If an analogy in human affairs were sought, the creation of a mechanical thing, the atom bomb, and its significance to man's survival, could be likened to that of a high dam and the survival of migrating fish. Each is capable of wiping out whole races at a single blow. Each creates problems in life, and its requisite adaptations, far beyond the "weapon" itself. The solution to useful outlets for these creations without being detrimental to life is not "just around the corner." It is fortunate that the atom bomb has not been placed in the stream of human life as often as high dams have been placed in the stream of salmon migration.

BIBLIOGRAPHY

Brett, J. R. Skeena River sockeye escapement and distribution. J. Fish. Res. Bd. Can. 8(7), 453-468, 1952.

Brett, J. R. and D. MacKinnon. Experiments using lights and bubbles to deflect migrating young spring salmon. Prog. Rept. Pac. Coast Stns., 92, 14-15, 1952.

Brett, J. R. and J. A. McConnell. Lakelse Lake sockeye survival. J. Fish. Res. Bd. Can. 8(2), 103-110, 1950.

Burner, C. J. Vertical distribution of downstream migrating chinook salmon fingerlings in the Bonneville forebay, with a note upon the rate of migration. Memorandum, Fish and Wildlife Service, Seattle, 1-11, 1949.

Foerster, R. E. The relation of temperature to the seaward migration of young sockeye salmon (*Oncorhynchus nerka*). J. Biol. Bd. Can., 3(5), 421-438, 1937.

Groody, T., A. Loukashkin and H. Grant. A preliminary report on the behaviour of the Pacific Sardine (*Sardinops caerulea*) in the electric field. Proceedings California Academy of Sciences, 27(8), 311-323, 1952.

Shepard, M. P. The resistance and tolerance of young speckled trout to low oxygen conditions. MS. Dept. of Zoology, Univ. of Toronto, 1953.

ited from The Canadian Field-Naturalist Vol. 66, November-December, 1952 No. 6

NOTES ON FISHES COLLECTED FROM LAKE WINNIPEG REGION[1]

J. J. KELEHER

Central Fisheries Research Station, Winnipeg, Manitoba

HE MOST RECENT CHECKLIST of Manitoban fishes is Hinks (1943). It is d partly on literature records, some of h are disputed (Hubbs, 1945). The dis- tion of many species is generalized tends to conceal our ignorance of their is occurrence. The cautious presentation of Manitoban distributional records in Dymond (1947) reveals the paucity of collected material. For these reasons, collecting fishes from this region is worthwhile.

Field studies for a research project of the Central Fisheries Research Station, Winnipeg, provided the opportunity for collecting specimens. The majority of the fish were

for publication, April 28, 1952.

collected by J. E. Matheson and the writer. The contribution of specimens by L. C. Hewson, K. G. Roberts and K. H. Doan is gratefully acknowledged. Useful suggestions for the improvement of the manuscript were provided by R. M. Bailey and G. H. Lawler.

The species list which follows is based on the specimens listed in Table 1 and does not contain all the species collected. Commercial fish generally are omitted and four other abundant species are not treated. These are *Notropis hudsonius*, spot-tail minnow, *N. atherinoides*, emerald shiner, *Percopsis omiscomaycus*, trout-perch and *Boleosoma nigrum*, Johnny darter. The table presents for each locality the number of fish, range in length and the date collected. Length is the straight line distance from the tip of the snout to the end of the middle caudal fin rays. The latitude of the localities are as follows: Red River, 49° 48′ and 50° 6′, Victoria Beach, 50° 42′, Black Island, 51° 12′, Loon Straits, 51° 32′, Bullhead, 51° 35′ Black Bear Island, 51° 46′, Dauphin River, 51° 58′ Spider Island, 53° 30′ and Warren Landing 53° 42′.

All fish listed in Table 1 have been deposited in the Royal Ontario Museum of Zoology and Palaeontology.

1. Ichthyomyzon castaneus Girard — Chestnut lamprey.

The lamprey from the Red River was collected between Selkirk and St. Andrews Locks. It was attached to a pike which was caught by angling. The Black Island specimen was caught in a commercial gill-net. This species appears to have a very limited Canadian distribution. Hubbs and Trautman (1937) report it from Lake Manitoba, and accept literature records from the Assiniboine and Red Rivers. Hinks (1943) states that it is abundant in the Winnipeg River.

2. Hiodon tergisus Le Sueur — Mooneye.

The mooneye and goldeye, *Amphiodon alosoides* both occur in Lake Winnipeg.

3. Rhinichthys cataractae (Valenciennes) — Longnose dace.

Approximately 10 individuals collected at Black Bear Island possessed a bright orange tinge on the pectoral fins and premaxillary. At every locality these minnows were seined on a rocky bottom.

4. Notemigonus crysoleucas (Mitchill) — Golden shiner.

The two specimens were collected in four feet of water at the mouth of the Mukatawa River. This record extends the Mani range since Hinks (1943) reports th currence of the golden shiner only "a the southern half of Lake Winnipeg."

5. Ictalurus punctatus (Rafinesque)—Ch cat.

These fish, collected in gill-nets, ar common at Victoria Beach. The explan for the change in the trivial name o species is given in Speirs (1952).

6. Ameiurus nebulosus (Le Sueur) — bullhead.

Schools of young bullheads frequentl observed in quiet bays at Victoria Hinks (1943) states that *A. melas*, the bullhead also occurs in Manitoba. Dy (1947) does not give any Manitoban butional records for this species. Spec if collected should be retained.

7. Schilbeodes mollis (Herman) — Ta madtom.

This species was collected by still f with earth-worms at the junction of th and Assiniboine Rivers, Winnipeg. On at Black Bear Island was taken at a de 33 feet. The others were obtained at th face in shallow water. Hubbs and (1947) list this species from the Red system of North Dakota. Hinks (1943) that it occurs occasionally in the Re Assiniboine Rivers. The Lake Winnipe cord is an extension of known distribu

8. Imostoma shumardi (Girard)—River

The Mukathawa River specimens collected either in the river mouth river proper. There is no record of the date collected but it was between Ju and July 31, 1947. Another fish taken river in 1947 was identified by Dr. Scott, Toronto. These records exten northern distribution given by Hinks *Etheostoma guntheri* Eigenmann and mann is treated by Hinks (1943) as onym of *Hadropterus maculatus* (Girard Black-sided darter. This appears to be ror since Hubbs and Greene (1928) Carlander (1941) regard *guntheri* as onymous with *Imostoma shumardi*.

9. Percina caprodes (Rafinesque)—Log

At Victoria Beach this species wa lected from a sandy bay; at the other ities it occurred on rocky bottom.

10. Poecilichthys exilis (Girard)—Iowa

The single specimen was obtained f small pool at Black Bear Island.

Table 1. Records of fish collected from Lake Winnipeg region

Species and locality	No. of fish	Range in length	Date collected
I. castaneus			
Red River	1	245	4/18/51
Black Island	1	255	1/ 9/52
H. tergisus			
Victoria Beach	10	47-61	7/21/51
R. cataractae			
Bullhead	23	36-68	7/29/51
Black Bear Island	30	35-73	7/21 & 28/51
Warren Landing	9	39-94	7/15/51
N. crysoleucas			
Mukatawa River	2	93-95	6/30/47
I. punctatus			
Victoria Beach	5	248-356	9/2 — 28/51
A. nebulosus			
Victoria Beach	5	32-42	8/23/47
S. mollis			
Red River	5	82-98	5/10/51
Black Bear Island	3	91-100	7/ 8 — 26/51
I. shumardi			
Bullhead	3	51-57	7/29/51
Mukatawa River	6	32-36	—/—/47
P. caprodes			
Victoria Beach	5	36-51	8/21/51
Bullhead	9	54-80	7/29/51
Black Bear Island	14	55-82	7/21 & 28/51
P. exilis			
Black Bear Island	1	44	7/28/51
C. bairdi			
Loon Straits	2	42-49	6/18/51
Black Bear Island	24	43-82	7/21/51
Dauphin River	1	71	2/ 7/45
Mukatawa River	1	76	7/22/50
C. ricei			
Mukatawa River	1	—	—/—/47
P. pungitius			
Loon Straits	3	41-44	6/18/51
Black Bear Island	1	33	7/21/51
Mukatawa River	2	49-58	6/29/49
Spider Island	4	44-57	6/12/51
E. inconstans			
Black Bear Island	4	30-38	7/28/51

11. Cottus bairdi Girard—Muddler.

All were taken in Lake Winnipeg. The Dauphin River fish was caught in a gill-net one mile off the river mouth, while the Mukatawa River sculpin was collected 7 miles west of the river mouth in 54 feet of water.

12. Cottus ricei Nelson—Rice's sculpin.

This sculpin was found dead on the river bank about 5 miles upstream from the mouth of the Mukatawa River.

13. Pungitius pungitius (Linnaeus)—Nine-spine stickleback.

No pertinent observations were noted.

14. Eucalia inconstans (Kirkland)—Brook stickleback.

This species was collected in the same small pool at Black Bear Island as the Iowa darter.

LITERATURE CITED

Carlander, Kenneth D. 1941. The darters (Etheostominae) of Minnesota. Proc. Minn. Acad. Sci. 9:41-48.

Dymond, J. R. 1947. A list of the freshwa fishes of Canada east of the Rocky Mo tains with keys. Misc. Publ. No. 1, Ro Ontario Museum of Zoology.

Hinks, David. 1943. The fishes of Manito Dept. of Mines and Natural Resour Province of Manitoba.

Hubbs, Carl L. and C. Willard Greene. 1 Further notes on the fishes of the Gr Lakes and tributary waters. Papers M Acad. Sci., Arts and Letters. 7 (192 371-392.

——— and Milton B. Trautman. 1937. A vision of the lamprey genus *Ichthyomy* Misc. Publ. Mus. Zoo., Univ. Mich., No.

——— 1945. Corrected distributional rec for Minnesota fishes. Copeia No. 1: 13-

——— and Karl F. Lagler. 1947. Fishes the Great Lake region. Cranbrook I Sci., Bull., No. 26.

Speirs, J. Murray. 1952. Nomenclature the channel catfish and the burbot North America. Copeia No. 2: 99-103.

From the Transactions of the Royal Society of Canada
Third Series, Volume XLVII, 1953

Wind Currents and Storm Effects on Water Movement at Sambro Lightship

BY

H. B. Hachey, F.R.S.C., and N. O. Fothergill

Ottawa
Canadian Committee on Oceanography
The Royal Society of Canada
1953

F.R.B. No. 358

TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA
VOLUME XLVII : SERIES III : JUNE, 1953
CANADIAN COMMITTEE ON OCEANOGRAPHY

Wind Currents and Storm Effects on Water Movement at Sambro Lightship

H. B. HACHEY,* F.R.S.C., and N. O. FOTHERGILL†

Introduction

OCEAN water is moved most variously by changing weather conditions, particularly by wind which acts on its surface. The water is usually in more or less distinct layers, as a result of heating and cooling near the surface and of either evaporation into the air or addition directly, or indirectly, of fresh water precipitated from the air. The lighter water is above and the heavier below. The layers move more or less independently from place to place. It is a most difficult matter to discover what factors are responsible for the particular movements observed at one place. Observations made of both surface current and wind at Sambro Lightship, off the entrance to Halifax Harbour, over a seven-month period in 1950 and 1951 illustrate this.

Observations in Halifax Harbour (Hachey, 1934b) had made it clear that information of an approaching tropical cyclone was given several days in advance by marked changes in bottom temperatures and salinities, brought about by shoreward movement of surface waters and offshore movement of deeper waters. This could be explained only on the basis of differences in atmospheric pressure over the ocean. Observations at Sambro Lightship also had shown (Longard and Banks, 1952) that shoreward movement of the light surface water is associated with strong easterly winds blowing more than half a day, which definitely piled these waters against the coast as evidenced by sea levels in Halifax Harbour.

Sambro Lightship is located in latitude 44°22′N., longitude 63°26′W. approximately ten miles off Chebucto Head at the entrance to Halifax Harbour. Simultaneous current and wind observations, totalling approximately 1500, were taken at Sambro Lightship between October 18, 1950, and May 19, 1951. These observations, instituted

*Chief Oceanographer, Canadian Joint Committee on Oceanography.
†Canadian Hydrographic Service, Department of Mines and Technical Surveys.

and supervised by the Canadian Hydrographic Service, were made by the officers of the Lightship.

In addition to these specialized observations relative to wind currents, observations on general weather and the temperature structure of the water column have been made over a period of twenty-three years by the officers of the Lightship. These general observations have been made relative to other investigations carried out by the Fisheries Research Board, Atlantic Oceanographic Group, the Naval Research Establishment, and the Meteorological Service.

As a result of these combined observations, we have considerable detailed data to determine for this area: (*a*) the surface currents and the effect of winds, and, (*b*) the effect of these winds and currents on the internal structure of the water column.

Method of Observations and Analysis

Using a 15 ft. current pole (Manual of Current Observations), the currents were measured hourly, and the wind directions were observed and recorded. In the analysis of these observations, the procedure followed was that of the Manual cited above. The method assumes that, given a large enough number of observations of currents when the wind is in a given direction and within a given range of velocity, the tidal currents will be essentially eliminated when an average is taken. Hence the mean value of all observations taken under specified wind conditions will give the approximate wind current for the mean wind speed of the range selected. While one year's observations are desired for this type of analysis, it is felt that the present data, extending over a period of seven months, are of sufficient accuracy.

The analysis classified winds as coming from sixteen directions, and falling within four velocity ranges, 5 to 15 mph. (miles per hour), 16-24 mph., 25-35 mph., and a summary of 5-35 mph. From the summary of 5-35 mph., which included virtually all observations taken, a vectorial average of all wind speeds and directions gives what could be called the permanent residual current. This current was then subtracted vectorially from the range of 5-35 mph. to give the true wind current for an average velocity of 20 mph. from the various directions. These wind current vectors, to be described later, are plotted in Fig. 1.

The permanent current velocity was subtracted from the arithmetic mean velocity of wind currents for particular wind velocity ranges, without regard to directions, to give the relationship between the true wind current and the wind velocity. This relationship is shown to be a straight line (Fig. 1).

It became apparent, in the analysis of the data, that when the wind velocity was in excess of 10 mph., the wind currents were sufficiently large to mask the tidal currents. For this reason the tidal analysis of the currents was limited initially to periods when the wind velocities were less than 10 mph., principally to observations taken when the wind was approximately 5 mph. The results of this analysis showed that another factor was present, namely the semi-permanent current régimes. By grouping the observations according to tide and the three different semi-permanent current régimes which were apparent, the fan-shaped variations as indicated in Fig. 1 were determined. By vectorially averaging these fan-shaped variations, the velocities and directions of the semi-permanent currents were determined.

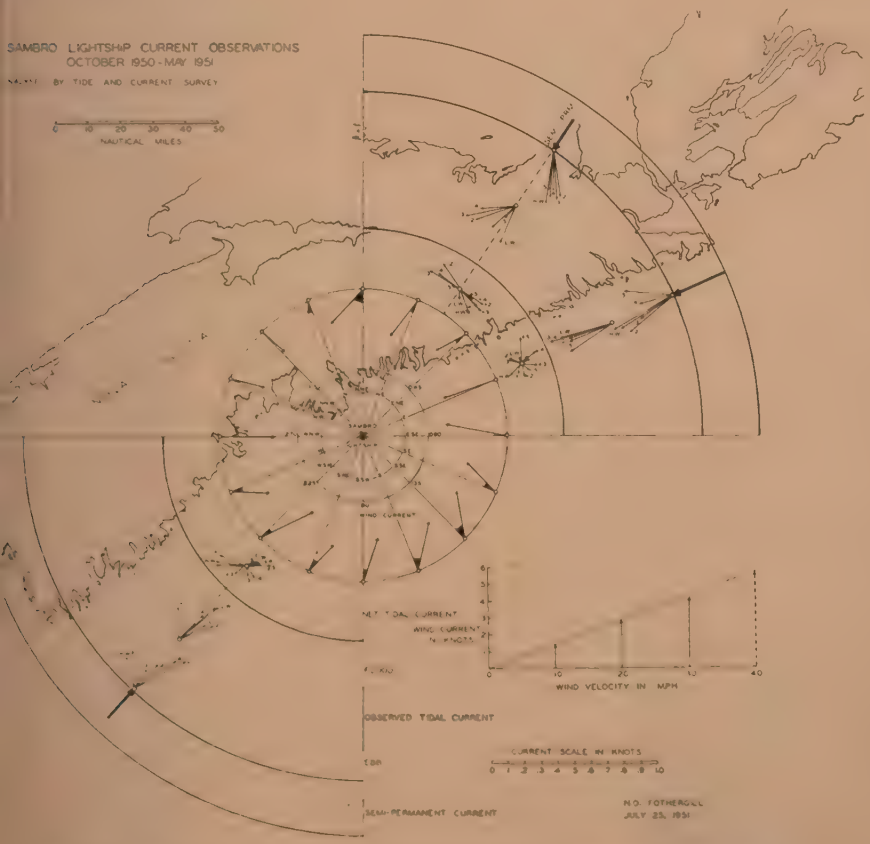


FIGURE 1.—Wind and tidal and semi-permanent currents at Sambro Lightship.

The Relationships between Wind and Current

The general arrangement in the illustration (Fig. 1) is one of concentric circles around the Lightship with the related coastline sketched in the background. All current vectors shown apply at the Lightship, despite their apparent geographical location.

The inner two circles are compass roses showing the sixteen points. The third circle shows as vectors the average wind currents both in velocity and in direction for the indicated wind direction, and corresponding to an average wind velocity of 20 mph. Right deflections of the wind current are shown by solid arcs, whereas left deflections have not been inked in. The influence of the land in shielding the water is readily seen in the northwest sector, where the wind currents have little or no right deflections from the wind directions. The graph showing the relationship between wind velocity and wind current strength is shown separately in the right-hand corner of the diagram. On the average, with the winds from the open sea, the current is deflected nearly twenty-one degrees to the right of the wind. With the winds from the land, the deflection is sometimes zero, but on the average about fifteen degrees to the right of the wind.

Between the fourth and fifth circles are shown the currents when the wind was less than 10 mph., which, during the period of observations, occurred about 15 per cent of the time. With low wind velocities, the flow past Sambro is of a semi-permanent nature, either from the northeast, east, or westsouthwest, and with apparently equal frequency.

From the current values at the various tidal intervals, as shown between the fourth and fifth circles, measured when the wind force was less than 10 mph., a theoretical tidal rose can be obtained by subtracting the effect of the semi-permanent current. The theoretical tidal roses obtained are shown between the third and fourth circles. Such theoretical roses are of doubtful value as they are rarely, if ever, observed, and by nature of the calculations are very approximate.

Between the two outermost circles are shown the three semi-permanent currents, which, as has been indicated, occur with equal frequency, and which are the resultants of observations made through tidal periods when the wind force was less than 10 mph. It would be of interest to know the characteristics of the waters involved in these semi-permanent currents in order to understand their nature, but in all probability they are features of a very local circulation. The current observations were made during the months when temperature contrasts in the water column were not large, and from the vertical temperature distributions it is impossible to draw any reasonable conclusions as to the circulation.

The observations have thus shown that:

(*a*) the surface current, both in direction and in magnitude, is strongly influenced by the wind force and direction, when the wind is greater than 10 mph.

(*b*) the surface current is either from the northeast, east, or westsouthwest, and thus rather steady or semi-permanent, when the winds are less than 10 mph., and,

(*c*) a given surface current at Sambro Lightship is a complex mixture of wind current, tidal current, and semi-permanent current.

Hence it is of some interest to consider the frequencies of wind direction and force in order to obtain the general features of the surface currents which prevail.

Wind Frequencies and Strengths at Sambro Lightship

Regular observations of wind force (Beaufort Scale) and direction are made twice daily at the Sambro Lightship throughout the year. In Figs. 2, 3, and 4, the wind frequencies of winds of force 3 (8 to 12 mph.) or higher, as observed by Sambro Lightship, are illustrated for the years 1950 2. The percentages of winds of less than force 3 are also given on the right-hand margins; they vary from 3.4 in February, 1950, to 68.3 in June, 1951.

There is considerable variation from year to year but generally winds of less than force 3 are in the minority. The percentage of winds of less than force 3 is less than 25 for the months of January, February, and December, 1950; of January, April, September, November, and December, 1951; and of January, February, March, September, October, and November, 1952. It is therefore generally in the summer months that the winds of less than force 3 are of comparatively greater significance. It follows from the analysis of the relationship between wind force and surface current that it is only in the summer months that the currents of a semi-permanent nature from the northeast, east, or westsouthwest are of more than slight significance.

As to the direction of winds of force 3 or greater, the prevailing directions are from the south, west, and northwest, with northerly and easterly winds becoming of more significance in the fall and winter months. Generally, with the winds from the west and southwest of force 3 or greater, the tendency of surface waters in the neighbourhood of Sambro Lightship is more or less to the east along the coast, and this tendency would prevail in the summer months more than 50 per cent of the time. At other times during the summer months, the semi-permanent current from the northeast or east or westsouthwest would

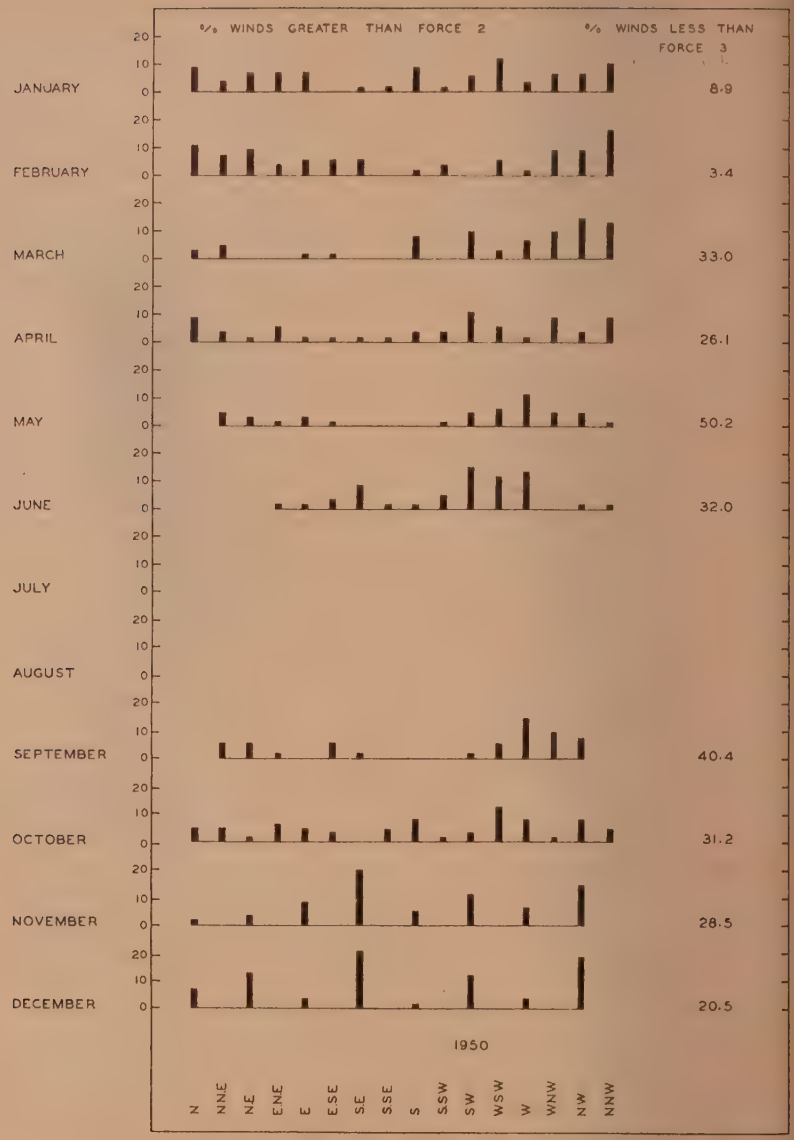


FIGURE 2.—Wind frequencies at Sambro Lightship, 1950.

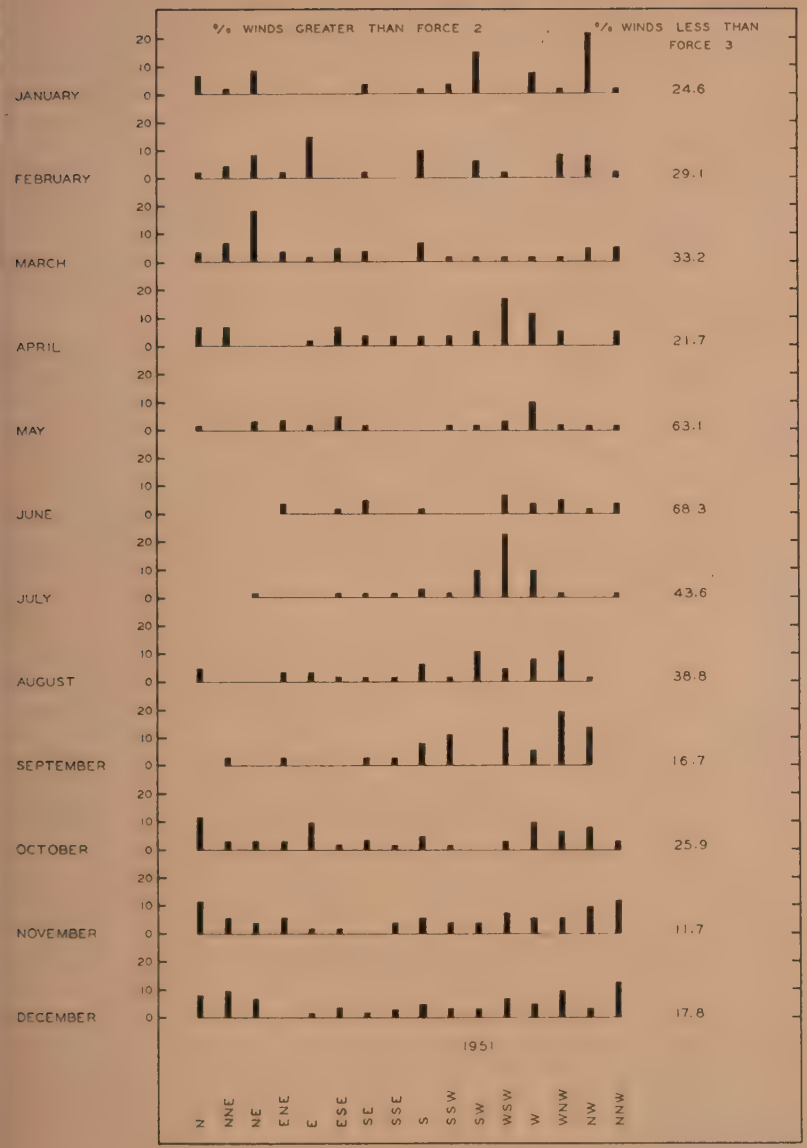


FIGURE 3.—Wind frequencies at Sambro Lightship, 1951.

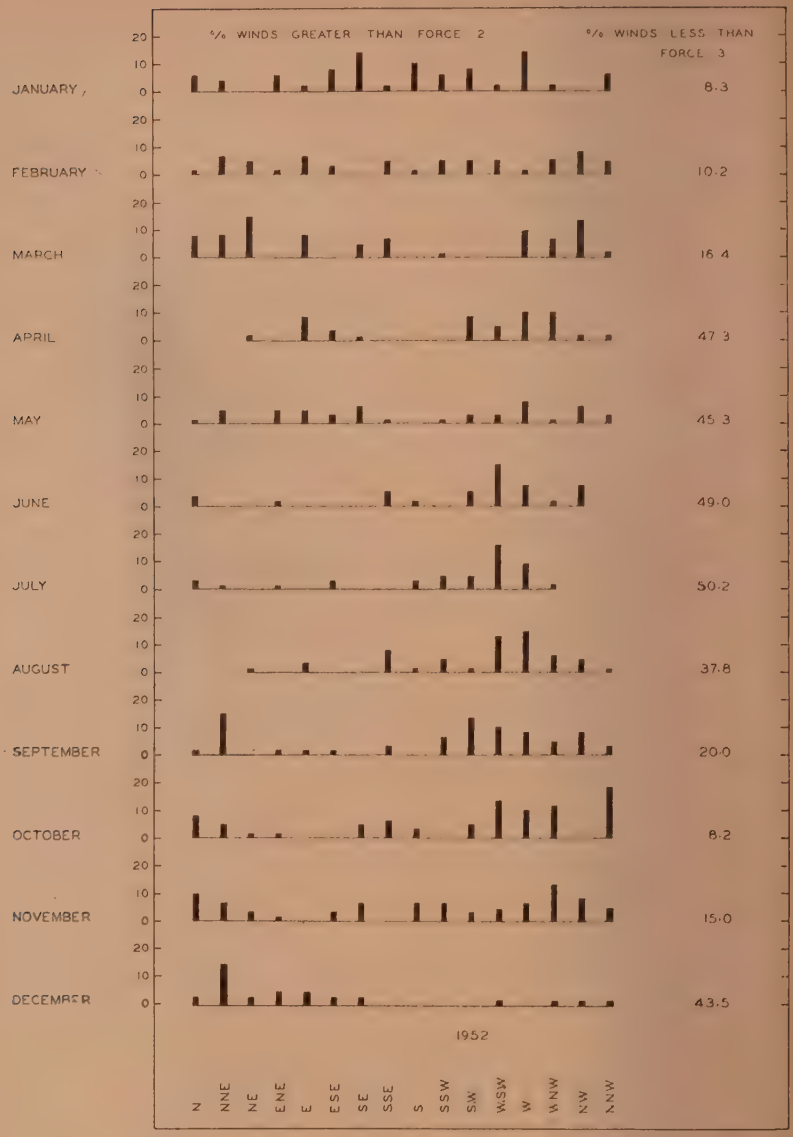


FIGURE 4.—Wind frequencies at Sambro Lightship, 1952.

prevail. In the winter months, the semi-permanent currents are of little significance, and the currents as determined by the wind might be in almost any direction.

Temperature and Salinity Changes in the Water Mass

The implications of extensive changes in the temperature and salinity of the water mass in the coastal area contiguous to Halifax Harbour, resulting from wind and or atmospheric pressure distribution have been considered by Hachey (1934a, 1935), Longard and Banks (1952), Trites (1951), and McLellan (1952). These authors have pointed out that these changes in temperature and salinity, most readily observed in the late summer and autumn months, are indicative of relative movements of the various density layers. They effect internal changes or adjustments in the densities in the water mass until the internal forces are in equilibrium with the extraneous forces acting at the surface. The latter consist of steep atmospheric pressure gradients and strong winds, which are associated with the tropical cyclones that are features of the weather over the Northwest Atlantic during late summer and autumn. In dealing with the action of these forces on the surface of the water there has been some difficulty in distinguishing between the direct action of local winds, and the possible direct or indirect effect of differences in atmospheric pressure over the neighbouring ocean. The early observations in Halifax Harbour (Hachey, 1934b) made it clear that advance information of an approaching tropical cyclone was given by the marked changes in bottom temperatures and salinities which occurred, brought about by the shoreward movement of surface waters with associated offshore movement of the deeper waters. This information is at times available several days before the arrival of the storm centre and its tropical wind system in the Halifax area (Hachey, 1938). Hence the phenomenon could be explained only on the basis of atmospheric pressure distribution over the ocean.

The effect of winds on the vertical structure of the water column, that is on the thickness of the various density layers, at Sambro Lightship has been dealt with by Longard and Banks (1952). These authors associate the shoreward movement of the light surface water, as shown by its increased thickness, with strong easterly winds blowing for more than half a day, which occurred simultaneously in their observations. The piling of the surface waters under such winds is confirmed by sea level observations recorded in Halifax Harbour.

It is suggested that the piling of surface waters toward the coast

in the vicinity of Halifax Harbour is to be detected more readily in Halifax Harbour than at Sambro Lightship. The thickening of the surface layer will begin near the shore and is readily measured by observations in Halifax Harbour. As the process continues, this thickening extends out to sea and, if the process is of sufficient magnitude, will be eventually measured at Sambro Lightship. On the basis of the time element involved, it is to be expected that the piling of surface waters by atmospheric pressure distribution offshore which is observed in the "calm before the storm" might eventually be observed at Sambro Lightship if not masked by the effect of the typically easterly winds which also move the surface layer against the coast and which rise as the storm centre approaches the vicinity of Halifax. Hence we find that in September, 1950, a very extensive thickening of the surface layer observed at Sambro Lightship can be ascribed to local easterly winds, while another in October, 1951, occurred when the winds had been less than force 3 for several days and hence without effect on the surface water.

In Figure 5, the changes in temperature at various depths at the Lightship, from September 7 to 30, 1950, are illustrated by the isotherms for 5, 10, and 15°C. The winds in both strength and direction are also indicated. Correlated with winds of force greater than 5 (19–24 mph.) from the eastward from September 11 to 14, is the downward displacement of the 5 and 10 degree isotherms as much as 150 feet. As the winds moderate and change direction from the eastward, the isotherms returned to their former levels. In terms of internal adjustment, the displacements of the isotherms downward indicate a thickening of the surface layers and a thinning of the bottom layers, and infer a shoreward movement of offshore surface waters, and an offshore movement of the deeper waters.

In Figure 6, the changes from September 20 to October 13, 1951, are similarly illustrated. On October 4, after a four-day period of light and variable winds, the 5 degree isotherm was displaced sharply downward by more than 200 feet, indicating movement shoreward of surface water. Two days later the 10 degree isotherm was similarly displaced downward by more than 100 feet when winds of gale force were blowing from the northeast and evidently brought much water of higher temperature from offshore.

During the periods of these internal adjustments in the water column, tropical cyclones were in formation and movement over the western North Atlantic. On September 12, 1950, the centre of the cyclone was located at latitude 41°N., longitude 65°W. The strong easterly winds observed at the Lightship were associated with this tropical cyclone and coincided with the internal adjustments at the

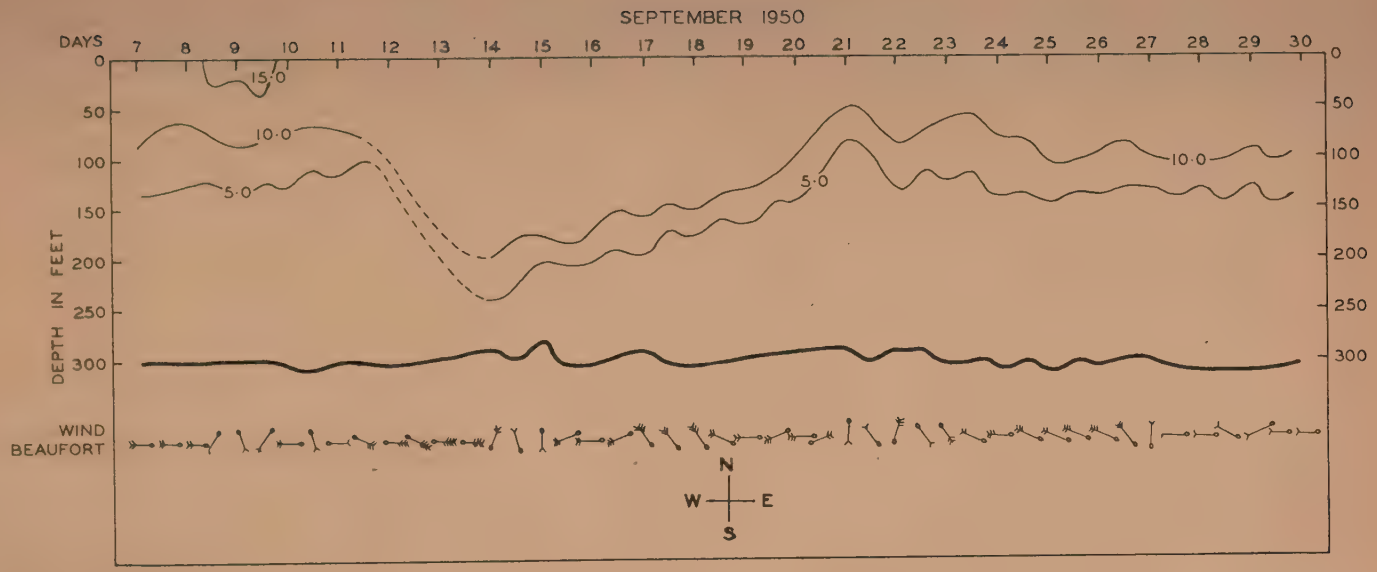


FIGURE 5.—The depth of isotherms at Sambro Lightship in relation to winds—September, 1950. (Arrows fly with the wind and the number of feathers designate the Beaufort number.)

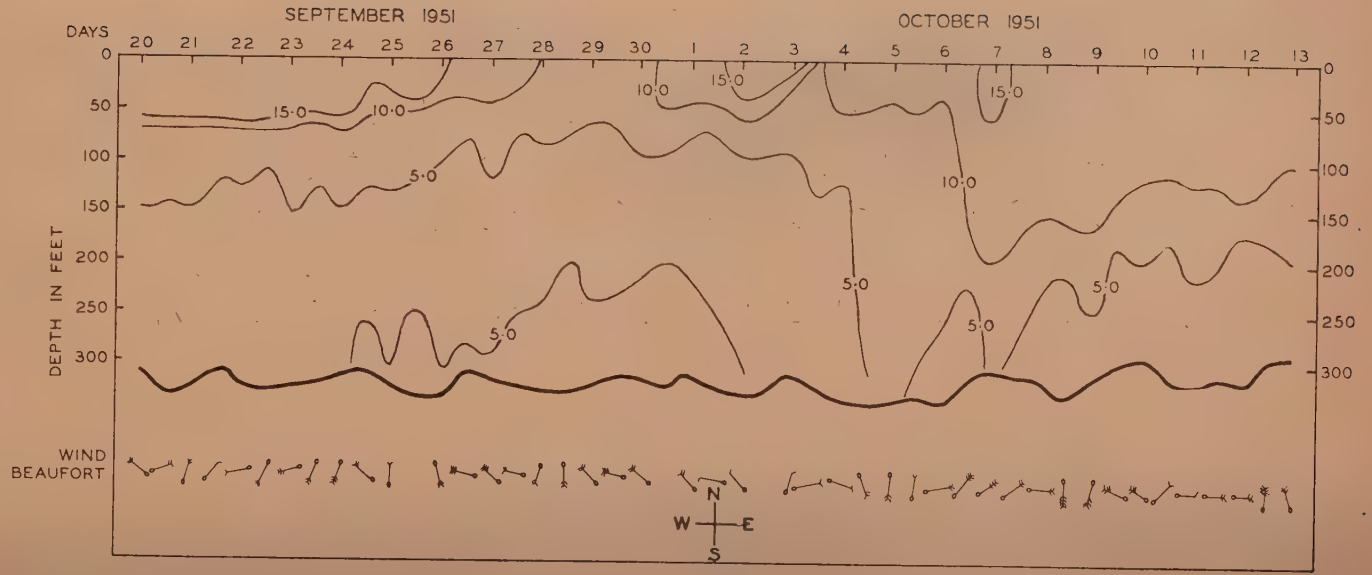


FIGURE 6.—The depth of isotherms at Sambro Lightship in relation to winds—October, 1951. (Arrows fly with the wind and the number of feathers designate the Beaufort number.)

Sambro Lightship. But on October 4, 1951, when internal adjustments in the water column at the Lightship were observed, the centre of a tropical cyclone was located at latitude 35°N., longitude 73°W., and the winds associated with this cyclone were not of any consequence until the 6th when they were of greater force than 4 and from the northeast. The intensities of the disturbances of September, 1950, and October, 1951, were approximately the same, with the centres following the typical paths of tropical cyclones, but in 1951 the changes in the water at the Sambro Lightship occurred two days earlier in the passage of the centre of the cyclone northeastward along the coast.

Discussion

There is little in the weather maps to indicate why the internal adjustments within the water column at Sambro Lightship should have been earlier in October, 1951, than in September, 1950, in the course of the storm centre along the coast. However the following explanation is offered.

We put forward the thesis that the semi-permanent currents from the northeast, east, and westsouthwest, as observed when the winds are less than 10 mph., are local features of the general circulation of the waters over a large area. One of the factors determining this circulation is the atmospheric pressure distribution, and as these pressure gradients are comparatively intense during the formation and movements of a cyclone, a very typical water circulation is associated directly and indirectly with the cyclone. Of the semi-permanent currents observed at the Sambro Lightship, currents from an easterly direction are found to be effective in causing a "piling" of the lighter and less saline waters near the coast with consequent removal of heavier and more saline waters. This process, which can be underway before the storm arrives, will be intensified by the easterly winds that occur when the storm centre arrives in the vicinity. The intensity of the storm, the path followed by the centre of the disturbance, and its rate of movement determine whether the replacement process of the waters in the Halifax region will extend to the location of the Sambro Lightship before the storm centre reaches the area. On this basis, the difference in detail between the tropical cyclone of September, 1951, and that of October, 1950, can be explained.

It is regrettable that the wind currents at Sambro Lightship were not observed during the months of August, September, and October in 1950 and 1951, seeing that in those months tropical cyclones are features of the weather, and temperature contrasts in the water column simplify the assessment of water replacements. It would be of particular interest, too, to have had details of the semi-permanent

currents during the period of formation and subsequent movement of tropical cyclones.

Summary

1. A given surface current at Sambro Lightship is a complex mixture of wind current, tidal current, and semi-permanent current.

2. The surface current, both in direction and in magnitude, is strongly influenced by the wind force and direction, when the wind is greater than 10 mph.

3. When the wind is less than 10 mph., the surface current is either from the northeast, east, or westsouthwest.

4. It is suggested that a current from an easterly direction is set up in association with the formation and subsequent movement of a tropical cyclone and that this current brings about replacement of waters, which, observed in Halifax Harbour, gives advance information on an approaching storm.

5. Large-scale internal adjustments in the water mass at Sambro Lightship, as shown by extensive displacements of the 5 and 10 degree isotherms, may be the result of either the direct action of local winds or the indirect action of atmospheric pressure distribution. Both actions have been observed.

Acknowledgment

This paper is published with the permission of the Joint Committee on Oceanography and the Canadian Hydrographic Service. The constructive criticisms of Dr. A. G. Huntsman, R. B. Lee, and C. M. Cross are gratefully acknowledged.

REFERENCES

Hachey, H. B. (1934a). North Atlantic cyclones and coastal waters. Fish. Res. Bd. Can., Prog. Rep. (Atl.) no. 11: 6–9, April.

———(1934b). The weather man and coastal fisheries. Trans. Amer. Fish. Soc., **64**: 382–9.

———(1935). The effect of a storm on an inshore area with markedly stratified waters. J. Biol. Bd. Can., **1** (4): 227–37.

———(1938). "Jellyfish" forecast the hurricane of September 21st. Fish. Res. Bd. Can., Prog. Rep. (Atl.) no. 23: 13–15, November.

Longard, J. R. and Banks, R. E. (1952). Wind-induced vertical movement of the waters of an open coast. Trans. Amer. Geophys. Union, **33** (3): 377–80.

McLellan, H. J. (1952). Fluctuating inshore water temperatures in the autumn. Fish. Res. Bd. Can., Prog. Rep. (Atl.), no. 33: 3–5.

Trites, R. W. (1951). Water replacements on the Scotian shelf. Fish. Res. Bd. Can., MSS report no. 418.

United States Dept. Commerce, Coast and Geodetic Survey (1938). Manual of current observations. Special Publ. no. 215, 75 pp. Washington.

Reprinted from
THE JOURNAL OF WILDLIFE MANAGEMENT
Vol. 18, No. 1, January, 1954

EFFECTS OF COMPENSATORY MORTALITY UPON POPULATION ABUNDANCE

W. E. Ricker

Pacific Biological Station, Nanaimo, B. C.
Fisheries Research Board of Canada

INTRODUCTION

The abundance of an animal popula-
on at a given moment is the resultant
innumerable factors of the animate
d inanimate environment. However
e general level about which it fluctu-
es is determined only by the factors of
ortality whose effectiveness varies with
ock density (Nicholson, 1933). In order
play a part in population control, the
fectiveness of a factor must vary in the
rection of increasing the mortality rate
density increases; that is, it must be
ncurrent (Solomon, 1949) or com-
nsatory (Neave, 1953). Nicholson has
en criticized for using the word "com-
tition" to include all mechanisms of
mpensatory mortality, but if this is a
fficulty, it is merely a terminological
e and not a weakness of his views.

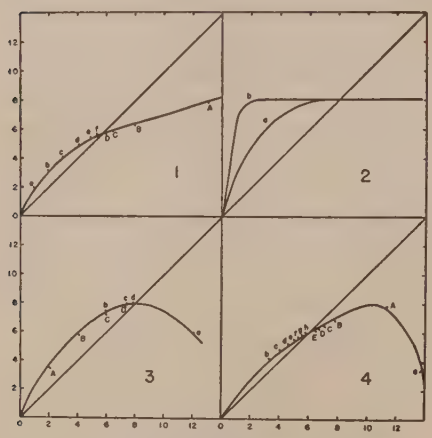
Much evidence indicates that mortality practically always bears most heavily upon the younger members of a population—the eggs and larvae, or newborn and juveniles, as the case may be. With increasingly severe competition at higher stock densities, the young stages increasingly bear the brunt of whatever mortality factors are in operation. Consequently for many populations we shall not go far wrong in assuming, as a first approximation, that all compensatory mortality occurs during the immature stages of the life history.

REPRODUCTION CURVES

On the basis just outlined, Figures 1–8 illustrate a series of possible relations between an existing stock (on the abscissa), and the future stock which the

existing stock produces during the current reproductive period (ordinate). These will be called "reproduction curves." For fishes it is most convenient to label the axes in terms of the mature eggs in present and future generations, respectively. The abscissa then represents the mature eggs produced by the current year's stock, and the ordinate represents the total of mature eggs produced by the progeny resulting from the current year's reproduction (obtained by summing over such period of time as the current year's brood is a component of future years' spawning stocks). In the absence of long-period trends, the average size of parental and filial egg production, defined as above, tends to balance out, although striking changes may occur between individual generations.

The straight diagonal in Figures 1–8 constitutes a useful boundary of reference which will be called the "45-degree line." Any curve lying wholly above thi line describes a stock which is increasin without limit, hence such a curve canno exist in practice. Similarly a curve be low the 45-degree line describes a stoc that will decrease to zero in a few genera tions. The 45-degree line itself woul describe a stock in which density dependence is absent, the filial genera tion tending always to be equal to th parental, except as factors independen of density deflect it. Such a stock woul have no mechanism for the regulation o its numbers: if only density-independen causes of mortality exist, the stock ca vary without limit, and must eventuall by chance decrease to zero. Thus th only necessary qualification of a repro duction curve is that it must cut th 45-degree line at least once—usuall only once—and it must end below an to the right of that line.



FIGS. 1–4. Stock-reproduction relationships characterized by a stable equilibrium. Abscissa: number of eggs produced by parent stock in a given year; ordinate: number of eggs produced by the progeny of that year.

POPULATION CHANGES IN THE ABSENC OF RANDOM EFFECTS

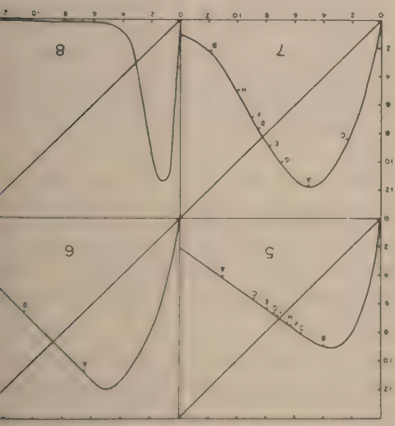
SINGLE AGE AT MATURITY. For popu lations in which there is a single age a maturity, that is, no mixing of genera tions, the curves of Figures 1–8 can b used directly to plot the trend of change in population abundance determined b the reproduction curve. The variou letter sequences show some possibl routes that a population could trace In every case, the point where the re production curve cuts the 45-degree lin is an equilibrium position, with repro duction just balancing mortality.

In Figure 1, an initial deflection o abundance to either side of the equilib rium point is followed by a gradua asymptotic return to equilibrium, fo example by paths A-D or a-f. In Figur 2a things work the same way to the le

the equilibrium point; to the right of any deflection, no matter how great, returned to equilibrium in a single neration. In Figure 2b deviations to left, as far as 2.5 units of stock, are o returned immediately to the equirium level.

In Figure 3 the equilibrium point is at top of the dome of the reproduction rve. The curve resembles 1 as regards lections to the left of the equilibrium int; but a displacement to the right is lowed by an immediate return across 45-degree line to the ascending limb, er which it "climbs" this limb to the uilibrium point (a-d). The curve of gure 4 is similar, but the dome lies to right of the 45-degree line; A-E and are possible paths to the equilibrium int.

In Figure 5, a stock deflected from uilibrium to any position along the scending limb will oscillate back and th about the equilibrium point with creasing amplitude, for example by



gs. 5–8. Stock-reproduction relationships which there is an oscillating equilibrium, or 5) an oscillating approach to stable equilibrium. Axes as in Figures 1–4.

the route A-I. If the deflection is great enough, the stock may have to climb the left limb before it is swung over to the right limb and begins the oscillating phase.

In Figure 5 the right limb has a downward (negative) slope less than unity. In Figure 6 this slope is exactly -1 after the dome is passed. Here any moderate deflection along the straight part of the right limb results in a swing back across the 45-degree line of exactly the same magnitude, so that the deflection tends to be perpetuated indefinitely; for example, A and B are two such conjugate points. The intersection of the 45-degree line is here a point of "indifferent" equilibrium: it is itself stable, but there is no inherent tendency for the stock to return to that level.

Finally, when the downward slope of the right limb of a reproduction curve is greater than unity, equilibrium at the 45-degree line is not merely indifferent, it is unstable. That is, any deflection from equilibrium, no matter how small, initiates a series of oscillations along the right limb whose amplitude increases until the dome of the curve is reached or surpassed. The latter event usually sends the stock back to the right limb and the cycle begins again. No matter where they begin, all such cycles eventually reach the dome of the curve, and a stable oscillation series is established for which the dome is a convenient starting point. The cycle in Figure 7 is A, B, C, D, E, F, G, H, A, etc. The number of stages in this cycle depends upon the exact shape of the curve, chiefly upon whether or not one stage lands close to the 45-degree line. Figure 8 represents a more extreme situation, in which substantial reproduction is obtained over only a

narrow range of stock densities considerably below the equilibrium level, and the stock would be subject to violent oscillations.

MULTIPLE-AGE SPAWNING STOCKS. When a spawning population consists of two or more age-groups, the young produced in a given year contribute to the stock of more than one future year, and the results of a deflection from equilibrium abundance are much modified. For fishes, a plausible example is one where each brood contributes to the spawning stocks of 4 future years, in the ratio 2:3:3:2, and first spawning occurs 4 years after a brood was produced. Figure 9 shows the result of an initial deflection of such a stock to an abundance of 12 on some of the reproduction curves of Figures 1–8. The course of events for the most part reflects what was learned in the single-spawning situation. Those based on Figures 1–6 all end up at the stable equilibrium level; this being reached by direct approach for 1, 2 and 3, with one hesitation for 4, and by a series of damped oscillations for 5 and 6. From Figures 7 and 8 series of undamped oscillations are obtained, that is, permanent cycles of abundance.

It may seem surprising that curve 6 too does not generate permanent oscillations, but the mixing of year-classes gradually brings the stock to a steady level, in the absence of any tendency toward divergence.

REPRODUCTION CURVE CYCLES. Permanent oscillations of the type produced by curves 7 and 8 will repay more extended discussion. Figure 10 depicts series of oscillations, based on Figure 7, but with each brood contributing to the reproductive stock for only two years. Time of first maturity is successively de-

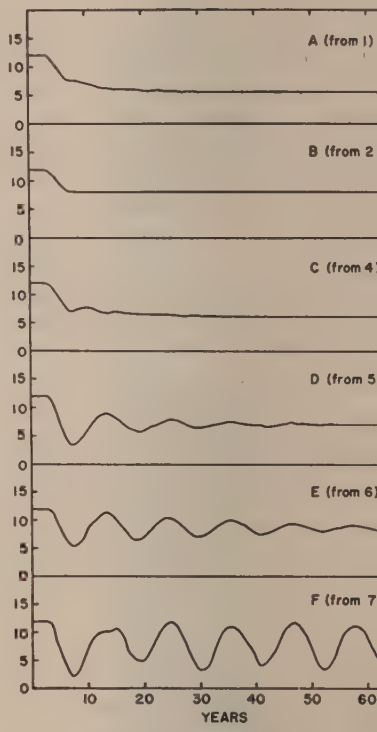
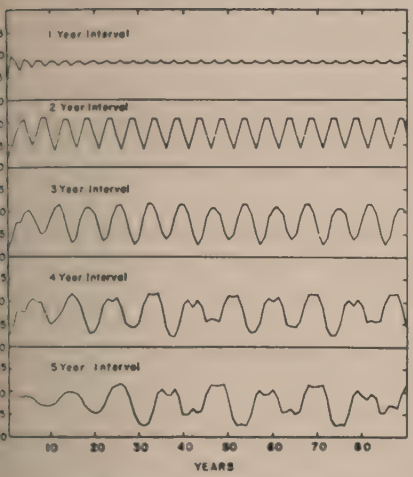


FIG. 9. Change in abundance of the sto
Figures 1, 2a and 4–7, following an
sustained deflection to an abundance
units, when the spawning stock is com
of four year-classes and first spawning
the fourth year after hatching. Abscissa:
(generations); ordinate: relative abun
(egg production) of the mature stock

layed one, two, or more years, so
the average contribution to reprodu
is made 1.5, 2.5, 3.5, etc., years
the brood in question existed as m
eggs. In every case stable cyclical
tuations exist, just as in Figure
Their period is in every case doubl
mean interval from egg to egg, th
3, 5, 7, etc., years. Other examples
that this can be taken as an approxi
general rule; though when the dist
tion of contributions to spawnin



ıg. 10. Population oscillations determined by ıe production curve of Figure 7, when there re two ages in the spawning stock and spawn- g first occurs after 1, 2, 3, 4 and 5 years, spectively, from deposition of the parental eggs. Axes as in Figure 9.

symmetrical, there is a slight deviation the direction of the mode.

The amplitude of the cycles of Figure 0 varies. If the animals are able to re- roduce in the year after they are born, mplitude is very small, but it quickly ıcreases if maturity is delayed. More enerally, appreciable amplitude in cycles f this type depends upon a preponder- nce of the reproduction of a brood ccurring after one or more reproductive eriods have elapsed from the time of its irth. A similar requirement of delay ırns up in the description of oscillatory ystems of other types (cf. Hutchinson, 948).

With the longer intervals of lag be- ween hatching and first spawning, the ycles of Figure 10 become less regular. linor peaks appear, and the pattern is uplicated more closely at 2-cycle inter- ıls, a feature which can be detected also in Figure 9F. However these tendencies become much less evident when more than two ages occur in the spawning stock. Only the major peaks would be detectable in any combination of average age of spawners and average age at first maturity that is apt to occur in nature.

Endless examples of reproduction-curve cycles could be constructed. Any desired combination of period and amplitude can be obtained, in more than one way, by selecting appropriate combinations of reproduction curve and age distribution of breeding. The general characteristics of such cycles can be summarized as follows:

1) Cycles occur when the outer part of the reproduction curve slopes downward, provided this slope begins at some point above the 45-degree line.

2) Cycles are damped and eventually disappear when the slope of the outer limb of the reproduction curve lies between 0 and -1. They are permanent when the slope lies between $-\infty$ and something a little less than -1, the exact critical limit depending upon the amount of mixing of ages in the spawning stock and the interval to first spawning.

3) Period of oscillation is determined by the mean length of time from parental egg to filial eggs, being close to twice that interval. It is independent of the exact shape of the reproduction curve, and is little affected by the number or distribution of ages in the spawning stock, provided there is more than one.

4) Amplitude of oscillation depends partly on the exact shape of the reproduction curve.

5) Amplitude of oscillation tends to

decrease with increase in the number of ages comprising the spawning stock.

6) Amplitude of oscillation increases rapidly with increase in number of years between parental egg and the first production of filial eggs, up to a limit imposed by the shape of the reproduction curve. When reproduction by a brood begins strongly in the first breeding period subsequent to its own birth, the oscillations are so weak that they could not be recognized in practice.

POPULATION CHANGES WHEN THERE IS RANDOM MORTALITY

The models discussed above, and the cycles which some of them generate, are likely to have only limited direct application to real populations. Superimposed upon the compensatory mortality described by the reproduction curves there are always variations in reproduction due to non-compensatory mortality. This non-compensatory mortality may itself vary systematically, for example when it reflects cyclic meteorological phenomena of cycles of other organisms. However, to a large extent it appears to be effectively random, and the latter situation only will be examined.

Random variations can be of all degrees. In extreme cases they produce, on the one hand, the extreme "dominance" of a year-class which occurs at infrequent intervals among some marine fishes and, on the other hand, a practically complete absence of reproduction in unfavorable years. However even the less spectacular random effects have a marked influence upon the actual course of population abundance. Consequently "stochastic" models, which take into account random effects, are neede describe most real situations.

Details of the construction of models will be presented in a later p but an example is shown in Figur It is based upon the same reprodu curve and arrangement of year-cl as the equilibrium phase of Curve Figure 9. Random effects were sel by lot from a normally-distributed p lation of such effects, and were bined with the reproduction indi by Figure 7. When the intensit random change was low, an av effect being a multiplication or div of the otherwise-indicated reprodu by 1.13, the cycle of events was much affected (Curve C). With an age change factor of 1.67, however turbance of the reproduction-curve was quite marked (Curve B), an

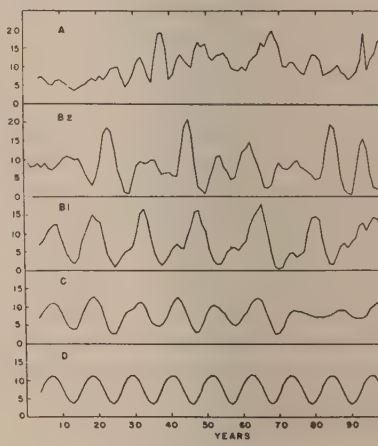


FIG. 11. Population fluctuations as deter by random factors only (curve A), by t production curve of Figure 7 (curve D by combinations of these (curves B an All curves except B2 start with the sam distribution in the population, this bein characteristic of the periodic series D; a continuation of B1. Axes as in Fig

basic periodicity was no longer recognizable.

Curves B and C of Figure 11 can also be regarded as indicating disturbance which the reproduction curve imposes upon the resultant of random environmental factors. Effects of the latter, operating alone, are shown in Curve A. In the mixed type, B, there is a much greater average amplitude of change, and a longer average distance between peaks of the "cycle", than in A.

Evidently the shape of the reproduction curve is of great importance in determining the nature of population fluctuations, even though the fixed periodicity that steep curves can generate under stable conditions may rarely be recognizable. Thus an investigation of the shapes of reproduction curves in nature can be expected to throw light upon some classes of observed fluctuations. Equally, it appears that harmonic or similar types of analysis, in which a sequence of censuses is resolved into a large number of periodicities, must fail to yield interpretable results when a reproduction curve plays the role it does in Figure 11B.

SUMMARY

Possible relationships between stock density and reproduction are examined in Figures 1–8. When reproduction reaches a maximum before the equilibrium point, and then declines, the stage is set for periodic changes in abundance. These are damped and tend to disappear if the descending limb of the reproduction curve has a slope between 0 and −1, but are self-perpetuating when the slope is steeper. For populations which have more than one age in the spawning stock, this leads to cycles whose period is twice the mean time from parental to filial egg production, provided there is at least one generation lag in achieving maturity. When there are moderate to large environmental influences upon reproduction, they interact with the reproduction curve to produce an irregular series of changes that differs in several respects from what either would produce by itself.

LITERATURE CITED

HUTCHINSON, G. E. 1948. Circular causal systems in ecology. Ann. New York Acad. Sci. **50**: 221–246.

NEAVE, F. 1953. Principles affecting the size of pink and chum salmon populations in British Columbia. J. Fish. Res. Board Canada **9**: 450–491.

NICHOLSON, A. J. 1933. The balance of animal populations. J. Animal Ecol. **2**: 132–178.

SOLOMON, M. E. 1949. The natural control of animal populations. J. Animal Ecol. **18**: 1–35.

[Reprinted from Food Technology, 1954, Vol. VIII, No. 1, Pages 15-19]

The Maillard Reaction in Flesh Foods[a]

H. L. A. TARR

Pacific Fisheries Experimental Station, Vancouver 2, B. C., Canada

(Manuscript received June 30, 1953)

Methods of determining Maillard browning in white fish muscle and of determining both free glucose and ribose in flesh foods are described. Evidence is presented which indicates that only the free and not the combined ribose in fish muscle takes part in Maillard reactions. It is shown that there is a relation between added ribose and the degree of browning in fish muscle and also between the indigenous ribose content and browning of the muscle of different varieties of fish. About five times as much glucose as ribose is required to cause the same degree of browning in fish flesh. It is shown that the free ribose and glucose content of different varieties of fish, and of beef, pork and veal is very variable, and that free ribose is only formed post mortem in fish muscle. The amount of ribose formed at 0° C. by fish and meats from added ribonucleic acid, ribotides, ribosides, adenosinetriphosphate and ribose-5-phosphate is recorded. Fish muscle forms ribose from all these substrates, beef and veal only from ribosides and ribose-5-phosphate and pork only from the last named compound. The enzymic formation of ribose in fish muscle is discussed with special reference to the riboside hydrolases concerned. The glucose and ribose content of meats is usually such as to indicate that significant Maillard reactions would occur only on extended heating, but no quantitative method of determining browning in these darker flesh materials was available. Physical methods of removing ribose from fish muscle as well as the possibility of destroying it enzymatically are discussed.

[a] Presented before the Thirteenth Annual Meeting of the IFT, Boston, Massachusetts, on June 23, 1953.

Issued as Paper No. 293 of the Canadian Committee on Food Preservation.

Printed in U.S.A. F R B No. 360

Little published information appears to be available concerning the occurrence of Maillard reactions in flesh foods which have been subjected to heat treatment, dehydration or both. Kaufman *(5)* stated that reactions of this type do occur in such foods, but neither described specific instances nor the mechanisms involved. Previous work by the writer *(8)* showed that the brown discoloration which developed frequently when the flesh of white fish was heated at 120° C. for one hour was apparently due to Maillard reactions, but the nature of the substance which contributed the aldehyde group was not determined. Further investigation showed that free D-ribose is, in most instances at least, the limiting factor in occasioning Maillard reactions in heated fish muscle *(9, 11)*, and the suggestion was made that this sugar arose through enzymic degradation of the nucleic acid of Hamoir's nucleotropomyosin *(2, 3)*. The occurrence of ribose as well as glucose in samples of beef and veal was also reported, as was the ability of the muscle tissues of certain fish to form D-ribose from added ribonucleic acid, ribotides and ribosides *(10)*. It is interesting to observe that in 1921 Berkeley *(1)* found that muscle tissue of certain fish contained from 350-410 μg. per g. of pentose. Since his samples were extracted with alcohol, free ribotides, ribosides and pentose would all have been accounted for. The present report deals with the post mortem occurrence of ribose and glucose in certain flesh foods; and more specifically with the formation of the first-named sugar in these foods, its role in occasioning Maillard reactions in fish flesh and with possible procedures for overcoming these reactions.

METHODS

The brown discoloration which occurred on heating fish flesh at 120° C. for one hour in an autoclave was determined quantitatively as follows. The cooked flesh was packed tightly into small dishes so that the surface was as level as possible and of uniform colour. The percent reflectancy of the sample was then referred to that of an arbitrary standard prepared by blending together 2.5% of block magnesium carbonate and 4% of high viscosity carboxymethylcellulose (Hercules) in water. The percent reflectancy of each sample was referred to that of the standard set at 100%, using a reflectance accessory with a Beckman model DU spectrophotometer and a wavelength of 500 mμ.

The total ribose content of fish muscle was determined using trichloracetic acid extracts and the Mejbaum orcinol reaction, as described by Hamoir *(2)*. The method used for determining free

ribose in initial experiments was described previously *(11)*. The following technique, employed in the present experiments, proved equally accurate, much more rapid, and permitted determination of both ribose and glucose. The flesh sample was blended with 9 volumes of 95% or absolute ethanol, or, in cases where the ribose or glucose content of samples was high, mixing with an equal volume of alcohol, and centrifuging proved satisfactory. With the first modification the blended mixture was filtered and 30 ml. evaporated to dryness in vacuo over H_2SO_4. The residue was mixed well with 1 ml. of cold water. It was found convenient to "spot" .01 ml. portions of this solution at 3 cm. intervals on Whatman No. 1 filter paper for chromatography, though, in a few instances where the sugar content was low, .02 ml. amounts were spotted in two separate additions. The papers were developed for 16 hours at room temperature with ethyl

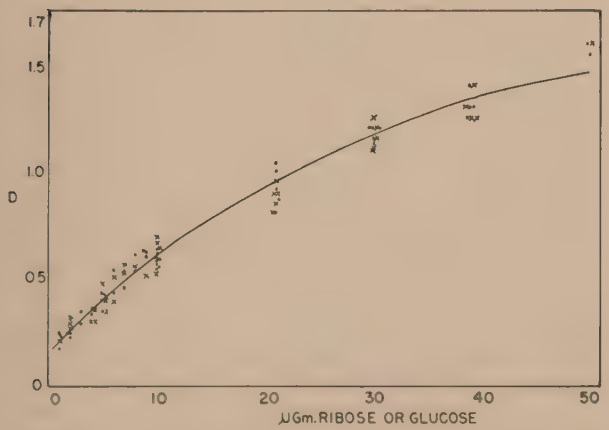


Figure 1. Curve for direct determination of ribose and glucose using a "spotometer." Glucose = x and Ribose = · applied singly or as mixtures. D (which denotes optical density) = $\log_{10}$ (I_o/I).

acetate : acetic acid : water solvent [Jermyn and Isherwood *(4)*], dried at room temperature, sprayed with aniline hydrogen phthalate solution *(7)* and heated 5 minutes at 105° C. to develop colour in the areas containing ribose and glucose. The papers were then cut lengthwise into strips 3 cm. wide so that the density of the coloured areas corresponding to ribose and glucose could be determined directly. It was found that this could be accomplished most conveniently by means of a "spotometer" [Paladini and Leloir *(6)*] used in a Beckman model DU spectrophotometer at 400 mµ wavelength and 2 mm. slit width. Figure 1 illustrates the standard curve used for both ribose and glucose determinations, the sugars being applied to the papers as solutions in 90% ethanol.

Though this method did not yield precise results it was found that usually ± 10% of added glucose or ribose could be recovered with muscle extracts prepared as above. From 0.25 to 0.5 μg. of the sugars could be detected visually on chromatograms, but, due to the variable absorbency of the filter paper itself (usually from about 0.025 to 0.125 density units), the spotometer could not be used with concentrations lower than about 1 μg. The most satisfactory range proved to be from 5 to 20 μg., and at these levels good recoveries of added ribose or glucose could be obtained if about 6 replicates were run. This technique has another great advantage over that previously employed, for alcoholic extracts of fish muscle contain varying proportions of ribosides which can be detected on the above chromatograms with ultraviolet light. In these chromatograms the zone corresponding to guanosine and cytidine (which have about the same R_f value in this solvent) is not far separated from that of ribose, and care must be observed in cutting chromatograms for ribose elution not to include ribosides since these naturally give a positive orcinol reaction. This difficulty is overcome by the direct determination method.

The various substrates employed in the experiments concerned with ribose formation and the reference sugars used were Nutritional Biochemicals Corporation products.[b]

RESULTS

Relation between total ribose and browning. Initial tests for total ribose in fish muscle indicated that there was no relation between this and the degree of brown discoloration caused by heating. The following experiments indicated that it was the free and not the total ribose which combined during heating of fish muscle.

Ten-gram portions of minced halibut muscle, which browned only slightly on heating at 120° C. for one hour (reflectancy value = 61% transmission), and of minced lingcod muscle which browned markedly during similar heating (reflectancy value = 39% transmission), were prepared both with and without 1500 μg. per g. of added ribose. The fish was heated in glass tubes at 120° C., samples being withdrawn at intervals of 1, 2 and 3 hours and the total ribose content determined. The results (Figure 2) showed that with halibut which contains little free ribose the total ribose content remained practically constant throughout the whole heating period, while that of the lingcod dropped during the first hour and thereafter remained constant. The

[b] Mention of commercial products in the technical pages of this JOURNAL is for purposes of identification only.

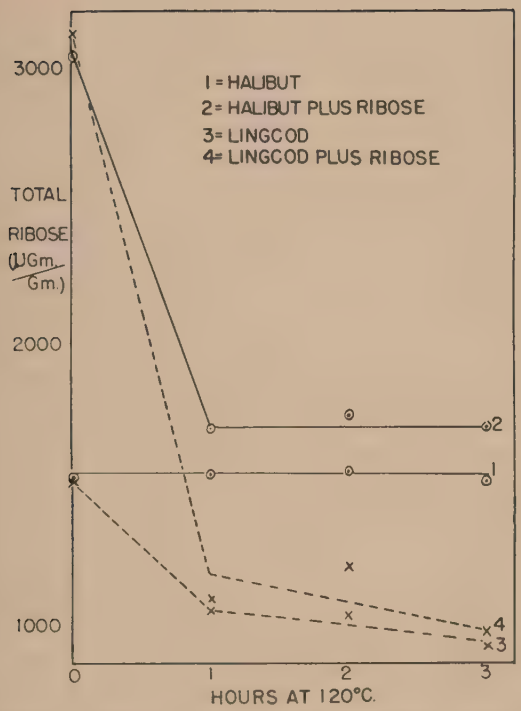


Figure 2. Effect of heating halibut and lingcod muscle with and without 1500 μg. per grm. of added ribose, on total ribose as determined by the Mejbaum method.

average drop in total ribose in the lingcod muscle was 540 μg. per g. With both halibut and lingcod all the added ribose was removed within one hour. In a previous experiment carried out along similar lines but using only one hour heating, it was shown that the fall in the total ribose content of both halibut and lingcod muscle was closely similar to the free ribose content as determined chromatographically employing the elution technique and the orcinol reaction *(11)*. It is assumed that free ribose combines with amino groups in Maillard reactions so that it can no longer be extracted with trichloracetic acid and determined by the Mejbaum reaction. An additional experiment showed that ribosides were unable to cause browning, for no decrease in reflectancy of halibut muscle was brought about by heat-

ing samples with uridine or guanosine in concentrations corresponding to 500 μg. of ribose per g. of flesh. It is of interest that the total ribose content of different samples of fish muscle has been found to vary from about 1500 to 3500 μg. per g.

Relation between free ribose and glucose and browning in fish muscle. The free ribose content of the muscle of different fish, and the degree of browning which occurred on heating samples of the muscle at 120° C. for one hour were determined. The results (Table 1) showed that there was a general tendency

TABLE 1

Relation between Maillard browning and the free ribose content of different fish muscle samples

Species	Ribose (μg./g.)	% Reflectancy
Mullet (freshwater fish)	<10	69
Halibut	35	63
Albacore tuna (fresh)	<10	57
Albacore tuna (defrosted)	32	56
Albacore tuna (defrosted, stored 1 week in ice)	29	59
Bonito	180	48
Lemon sole	140	40
Skipjack tuna	200	37
Lingcod	550	33
Red cod	240	28

for increased browning with an increase in the free ribose content. There was not an absolute agreement, but this can hardly be expected since Maillard reactions are complicated, and the rate of development of brown colour after the initial reaction of ribose and amino groups may not be the same with different muscle samples. That ribose and not glucose is the sugar mainly responsible for browning was shown by the following experiment.

Halibut muscle which contained 32 μg. per g. of free ribose and no appreciable glucose was heated at its natural pH with different amounts of ribose and glucose, and the reflectancy of the treated samples was determined. The results, given in Table 2, showed that about 5 times as much glucose as ribose was required to occasion the same degree of browning.

Unfortunately no test has as yet been evolved which will permit the determination of browning in flesh of pigmented fish such as salmon or in meats. In salmon,

TABLE 2

Comparison of Maillard browning in halibut muscle occasioned by added glucose or ribose

Concentration of sugar added (μg./g.)	Percent reflectancy of heated samples	
	Ribose	Glucose
None	67	67
50	65	66
100	62	67
200	59	67
300	56	67
400	53	64
500	47	61
1000	41	59

tests indicate that the ribose and glucose content are such that they are unlikely to occasion serious Maillard reactions *(vide infra)*, and, indeed, there is little indication that such reactions occur to any significant extent in canned salmon. With meats the ribose content is almost invariably low, and the glucose content is usually not high enough to suggest that it may cause serious browning under the heating conditions used in these experiments.

The ribose content of various samples of fish and meats. The ribose and glucose content of the muscle tissues of a number of samples of fish and meats, some of well-defined history, was investigated, and the results are tabulated (Table 3). It will be seen that the muscle of living fish frozen in liquid nitrogen contained no appreciable free ribose or glucose, and that in one of the species studied there was rapid accumulation of both sugars post mortem at 0° C. The flesh of lingcod in rigor mortis also contained no appreciable ribose or glucose, and the former accumulated rapidly post mortem. The glucose content of lingcod flesh post rigor was low. Only small amounts of ribose occurred in the muscle of 3 of 4 species of salmon (genus *Oncorhynchus*) studied, but significant concentrations of glucose were present. Considerable variation in sugar distribution in the muscle tissues of tuna species and of bonito was observed. Both skipjack and bonito had rather similar concentrations of ribose and of glucose, while the remaining species had considerably less. The samples of pork studied were free, or almost free, of ribose. Their glucose content was very variable, in one instance exceeding 1900 μg. per g. Certain of the aged beef and

veal samples contained ribose, but never in as high concentrations as those found in fish muscle. All beef and veal samples contained glucose in concentrations varying from 260 to 770 μg. per g.

Formation of ribose from ribonucleic acid, ribotides, ribosides, ribose-5-phosphate and adenosinetriphosphate. The formation of ribose from various nucleic acid fragments by muscle tissues was investigated in the following manner. Aqueous solutions of

TABLE 3

Ribose and glucose distribution in fish and meat [the figures in parentheses were obtained by the elution technique and orcinol reaction (11)]

	Sugar content (μg./g.)[c]	
	Ribose	Glucose
Albacore tuna (fresh)	<10	190
Albacore tuna (defrosted)	(32)	.....
Albacore tuna (defrosted, stored 1 week in ice)	29	.....
Albacore tuna (dark lateral muscle)	26	<10
Bluefin tuna (defrosted)	40	52
Skipjack tuna (defrosted)	190	350
Bonito (defrosted)	180	310
Coho salmon (fresh market sample)	0	23
Pink salmon (fresh market sample)	20 (17)	740
Sockeye salmon (fresh market sample)	30 (55)	270
Red spring salmon (fresh market sample)	10 (16)	290
Lingcod (in rigor mortis)	0	0
Lingcod (same fish, muscle stored 20 hr. at 20° C.)	880	<10
Sculpin 1 (live fish frozen in liquid nitrogen)	0	0
Sculpin 1 (muscle stored 2 days at 0° C.)	(604) (636)	330
Sculpin 1 (muscle stored 4 days at 0° C.)	590	430
Sculpin 2 (live fish frozen in liquid nitorgen)	0	0
Sculpin 2 (muscle stored 2 days at 0° C.)	710	430
Sculpin 2 (muscle stored 4 days at 0° C.)	700	730
Tomcod (live fish frozen in liquid nitrogen)	0	0
Tomcod (muscle stored 2 days at 0° C.)	17	48
Halibut (fresh market sample)	42 (35)	34
Mackerel (California)	<10	450
Red Cod (fresh market sample)	310 (240)	70
Lemon sole (fresh market sample)	120 (140)	120
Lingcod (fresh market sample)	(525) (585)	30
Pork (market sample of loin chop)	<10	170
Pork (market sample of rib chop)	<10	1940
Pork (loin chop stored 2 days at 2° C.)	0	120
Pork (loin chop stored 9 days at 2° C.)	<10	0
Veal (shoulder chop, market sample)	90	450
Veal (rib chop, stored 2 days at 2° C.)	<10	370
Beef tenderloin (market sample)	91	680
Beef wing steak (steer, stored 2 days at 2° C.)	0	670
Beef wing steak (cow, stored 2 days at 2° C.)	<10	700
Beef front shank (stored 2 days at 2° C.)	<10	260
Beef brisket (stored 2 days at 2° C.)	<10	610
Beef T-bone steaks (stored 2 weeks at 2° C.)	200	770
Beef round steak (market sample)	125	550

[c] 0 = No detectable ribose on the chromatograms; <10 = trace of ribose which could not be determined accurately.

the substrates were prepared of such concentration that, if complete liberation of ribose occurred, there would be 2000 μg. of that sugar per g. of suspension when 0.5 ml. of the solution was incorporated in 1.5 g. of muscle. Where necessary the solutions were adjusted to about pH 7.0 with 1.0 N. NaOH. Barium was removed from barium ribose-5-phosphate solutions by addition of the calculated quantity of Na_2SO_4, centrifuging and washing the precipitate in the usual manner. Adenosinetriphosphate was used as the sodium salt. Since certain of the substrates are sparingly soluble in water, it was necessary to heat their solutions and incorporate them carefully in the chilled muscle samples so that the temperature of the mass would not be such as to destroy the enzymic activity. The muscle tissues were blended in the cold prior to use, 1.5 g. samples placed in 5 ml. beakers together with the substrate solution and stored at 0° C. for 3 or 5 days before determining the ribose content.

The results of this experiment (Table 4) show that fish muscle exhibited much more intense activity toward the various substrates as judged by ribose formation than did that of the mammals under the experimental conditions. The fresh lingcod was very active and formed ribose in approximately theoretical amounts, within the probable limits of accuracy of the method of estimation, from adenosine, inosine, xanthosine, cytidine, myoadenylic acid and ribonucleic acid. The rather great insolubility of guanosine probably contributed to its slower breakdown. In general the ribotides, other than the muscle adenylic acid, were less rapidly broken down than the ribosides, and this was also true of ribose-5-phosphoric acid. The defrosted lingcod and rock cod muscle tissues generally exhibited lower activity than the fresh muscle sample, perhaps partly because of the shorter incubation time at 0° C. Some curious discrepancies were evident. Thus with the defrosted lingcod muscle adenosinetriphosphate actually hindered the formation of ribose from indigenous substrates, and this appeared to be true to a lesser extent with xanthosine in the case of the defrosted rock cod muscle. It is evident that with the fish muscle samples a complex of enzymes is involved in the formation of ribose, and the evidence indicates that ribonuclease, phosphomono-

TABLE 4

Ribose formation by fish, beef, pork and veal from ribonucleic acid, ribotides, ribosides, adenosinetriphosphate and ribose-5-phosphate [d]

Substrate	Fresh lingcod [f]	Lingcod frozen 3 months at —20° C.[e]	Rock cod frozen 3 months at —20° C.[e]	Beef (mixed sample) [e]	Veal (mixed sample) [f]	Pork (Loin chop) [f]
None	600	700	1060	About 50	About 50	<25
Adenosine	2160	1920	1460	440	520	None
Guanosine	1600	920	720	200	250	None
Inosine	2170	1860	1620	470	350	None
Xanthosine	2150	1600	—120	250	290	None
Cytidine	2000	1390	450	<25	<25	None
Uridine	1160	360	230	None	None	None
Myoadenylic	1900	40	1260	None	None	None
Yeast adenylic acid	1100	1020	800	None	None	None
Guanylic acid	860	830	340	None	None	None
Cytidylic acid	560	90	130	None	None	None
Uridylic acid	630	80	—16	None	None	None
Adenosinetriphosphate	280	—430	1140	None	None	None
Ribonucleic acid	1800	660	460	None	None	None
Ribose-5-phosphoric acid	440	390	180	None	None	460

[d] The results given for each substrate represent the difference between the amount of ribose formed from that substrate and the corresponding control. The fish samples had pH values ranging from 6.8-7-1 and meat samples 6.6-6.8 at the conclusion of the experiment.

[e] Samples stored 3 days at 0° C. before ribose determined.

[f] Samples stored 5 days at 0° C. before ribose determined.

esterase, adenosinetriphosphatase and riboside hydrolase (or, possibly, riboside phosphorylase) enzymes may be included.

The beef and veal samples attacked the 4 purine ribosides and ribose-5-phosphate with the formation of a moderate amount of ribose, but the ribotides, ribonucleic acid and adenosinetriphosphate did not yield ribose under the experimental conditions. The pork muscle did not form appreciable amounts of ribose from any of the substrates studied except ribose-5-phosphate.

A study of the enzymes concerned in the degradation of ribonucleic acid and its various derivatives is being carried out with preparations made from fish muscle *(10)*. Protein fractions with about 50 times the activity of the whole muscle toward inosine and adenosine have been obtained from both lingcod and rock cod. One of these fractions caused ribose formation only from purine ribosides, while another attacked both the purine ribosides and the pyrimidine riboside cytidine, but not uridine. So far attempts to demonstrate the presence of a

riboside phosphorylase have not been successful, and it would seem possible that only nucleoside hydrolyase enzymes are involved in the formation of ribose from nucleosides by fish muscle. The work on enzyme fractionation is proceeding.

Prevention of Maillard reactions. Several possible methods of preventing or diminishing the severity of Maillard reactions in fish muscle suggest themselves. It was shown some time ago that leaching raw flesh in cold running water would eliminate the browning which occurred on heating it at 120° C. for one hour *(8)*. If the flesh is heated to a sufficient extent to coagulate the proteins, browning can be reduced due to loss of expressed liquid, but, since ribose probably combines with amino groups of the muscle proteins, and some of the liquid usually remains, browning will probably not be entirely eliminated. These leaching and heating methods may result in loss of desirable flavour constituents. It is possible that if fish flesh could be heated while still in rigor when free ribose has not formed Maillard reactions could be eliminated.

The most attractive way of overcoming browning in heated or dehydrated fish flesh would be the removal of free ribose by enzymic means, a method which appears to have proven successful in removing glucose from eggs to prevent Maillard reactions in the dehydrated product. At present a search is being made for an enzyme preparation which will render ribose inactive as far as the Maillard reaction is concerned. It has been found that lager beer yeast, *Lactobacillus pentoaceticus, Acetobacter suboxydans, Penicillium notatum, P. chrysogenum, Fusarium redolens* and *F. solani* all grow upon media containing ribose and decompose the sugar. Some exploratory work has been carried out with a view to obtaining an enzyme preparation which will possess activity sufficient to oxidize or otherwise remove ribose from fish muscle. This work is proceeding.

LITERATURE CITED

1. Berkeley, C. On pentose compounds in tissues of marine animals. *Trans. Roy. Soc. Canada,* **15**, Sec. V, 41-47 (1921).
2. Hamoir, G. Fish tropomyosin and fish nucleotropomyosin. *Biochem. J.,* **48**, 146-151 (1951).
3. Hamoir, G. Further investigations on fish tropomyosin and fish nucleotropomyosin. *Biochem. J.,* **50**, 140-144 (1951).
4. Jermyn, M. A., and Isherwood, F. A. Improved separation of sugars on the paper chromatogram. *Biochem. J.,* **44**, 402-407 (1949).
5. Kaufman, C. W. Common ailments of quality in processed foods. *Food Inds.,* **18**, 80-83 (1946).
6. Paladini, A. C., and Leloir, L. F. Detection of ultraviolet-absorbing substances on paper chromatograms. *Analyt. Chem.,* **24**, 1024-1025 (1952).
7. Partridge, S. M. Aniline hydrogen phthalate as a spraying reagent for chromatography of sugars. *Nature,* **164**, 443 (1949).
8. Tarr, H. L. A. The Maillard reaction in fish products. *J. Fish Res. Bd. Canada,* **8**, 74-81 (1950).
9. Tarr, H. L. A. Cause of the browning of certain heat-processed fish products. *Fish Res. Bd. Can., Prog. Rep. Pacific,* **92**, 23-24 (1952).
10. Tarr, H. L. A. Post mortem liberation of ribose in fish skeletal muscle. *Federation Proc.,* **12**, 279 (1953).
11. Tarr, H. L. A. Ribose and the Maillard reaction in fish muscle. *Nature,* **171**, 344-345 (1953).

RCTIC AND SUBARCTIC MARINE ECOLOGY: IMMEDIATE PROBLEMS

M. J. Dunbar*

Mur study of marine biology in the north has been pursued, in the past, mainly by the Scandinavian countries. In the northern waters which ndinavian biologists do not normally visit, and especially in the North erican Arctic, marine investigation is in its infancy, and has even lagged nd terrestrial ecology in the same area. As there are now signs that this lition is to be put back in balance, this is the proper time to review briefly most interesting results of the past and to point out the most promising s of study for the immediate future.

For the purposes of this paper the terms "arctic" and "subarctic", applied he marine environment only, are used as defined previously (Dunbar, a): the marine arctic being formed of those areas in which unmixed r of polar origin (from the upper layers of the Arctic Ocean) is found he surface layers (200–300 metres at least). Admixture of water of terri- us origin is ignored in this definition. The marine subarctic is defined ose marine areas where the upper water layers are of mixed polar and polar origin. By far the greater part of the marine subarctic lies on the ntic side, extending from the Scotian shelf and Hudson Strait to the nts and Kara seas, and including almost the whole coast of west Greenland, waters around Newfoundland and Iceland, much of the Norwegian Sea, the waters off the west coast of Spitsbergen. The southern boundary of marine subarctic is the limit of southward penetration of the arctic water; rly it varies seasonally and with the state of the climatic cycle. For the and rather ill-defined marine region south of the subarctic, the term real" is used here, but with that region we are not directly concerned. ould be added that the division employed here apparently applies less to le animals and plants, than to the plankton and nekton, because of local tions in summer. This does not disturb the general picture, and is ussed further below.

Production

The fact that this division between the marine arctic and subarctic is not rbitrary thing, but reflects a real and obvious difference in the biological duction of the two regions, points to this difference as one of the most esting things about the northern waters, and the study of the causes of difference has only just begun. The fact itself is quite evident: the great rctic belt across the North Atlantic area is one of the richest parts of

*Associate Professor of Zoology, McGill University.

Reprinted from "ARCTIC", Journal of the Arctic Institute of North America, Volume 6, Number 2, July 1953.

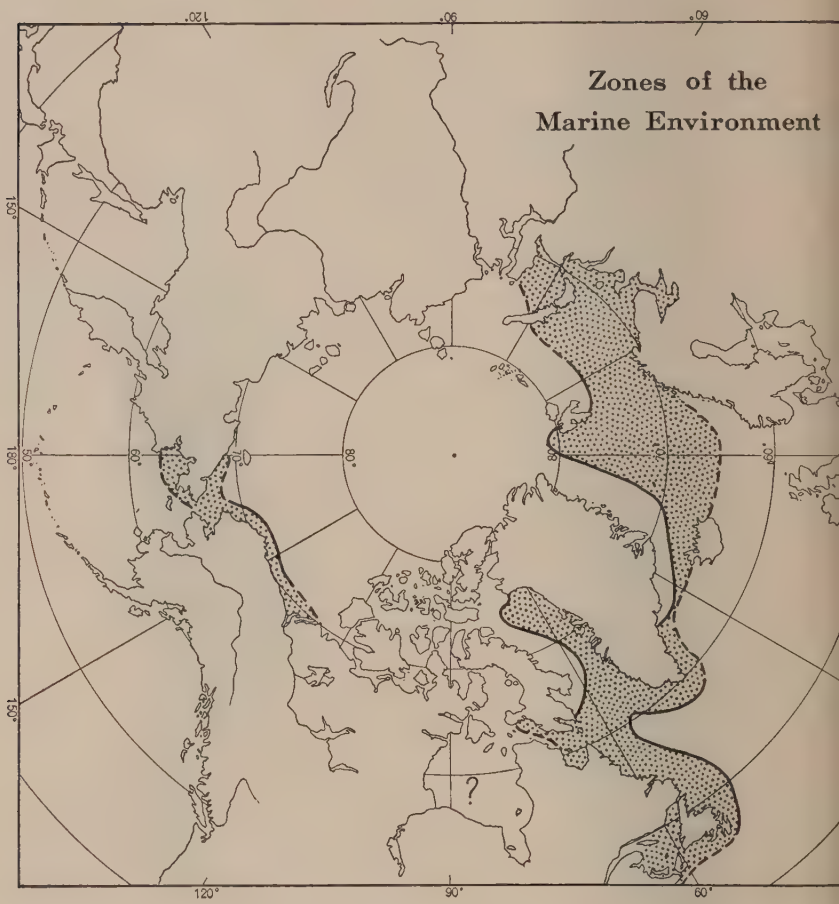
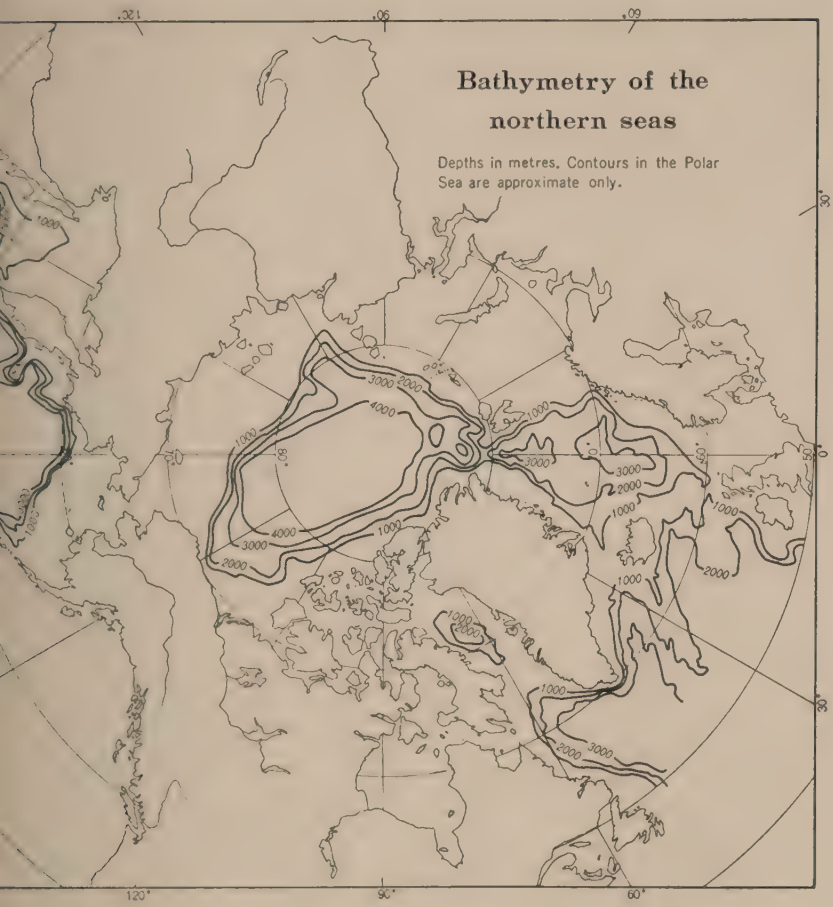


Fig. 1. Zones of the marine environment; the subarctic zone, as defined in the tex stippled. The lines of delimitation are approximate, and dotted lines indicate reg still in doubt. There is some evidence that the subarctic should extend farther sout the region southeast of Iceland, northern Scotland, and western Norway, and that coasts of Kamchatka and parts of the Seas of Okhotsk and Japan should also be inclu in the subarctic.

the oceans of the world, the home of fisheries of immense value, maintai by many nations of the Atlantic community. That these fish resources dependent upon plankton production is obvious, and the same is true of ot parts of the seas of great economic value, such as the subantarctic belt the region of influence of the Peru Current off the west coast of So

[1]Figures 1 to 4 are reproduced from drawings prepared for the author's chapters "Northern Waters" in the forthcoming volume 'Geography of the Northlands', ed by G. H. T. Kimble and Dorothy Good, to be published for the American Geograph Society by John Wiley and Sons.



2. Bathymetry of the northern seas. The four deep enclosed basins (Arctic Ocean, nland and Norwegian seas, and Baffin Bay) have many faunistic points in common, ugh separated by submarine ridges. Notice the Wyville Thompson ridge north of and and its extension to Iceland and east Greenland, also the similar ridge in Davis Strait. Both ridges rise to a water depth of about 600 metres.

erica. In fact the much higher plankton production in the subarctic, n compared with the arctic, is at once apparent in the field. The quan- ve measurement of this difference in production, however, is only now nning in certain parts of the north, and is one of the next steps to be n in the North American Arctic and Subarctic. The chemical and ical factors underlying the differences in production have also to be stigated. It may be that the high production in subarctic water is caused ly by the lifting of the temperature inhibition in water of arctic origin tic water being very cold, and therefore presumably a depressant upon

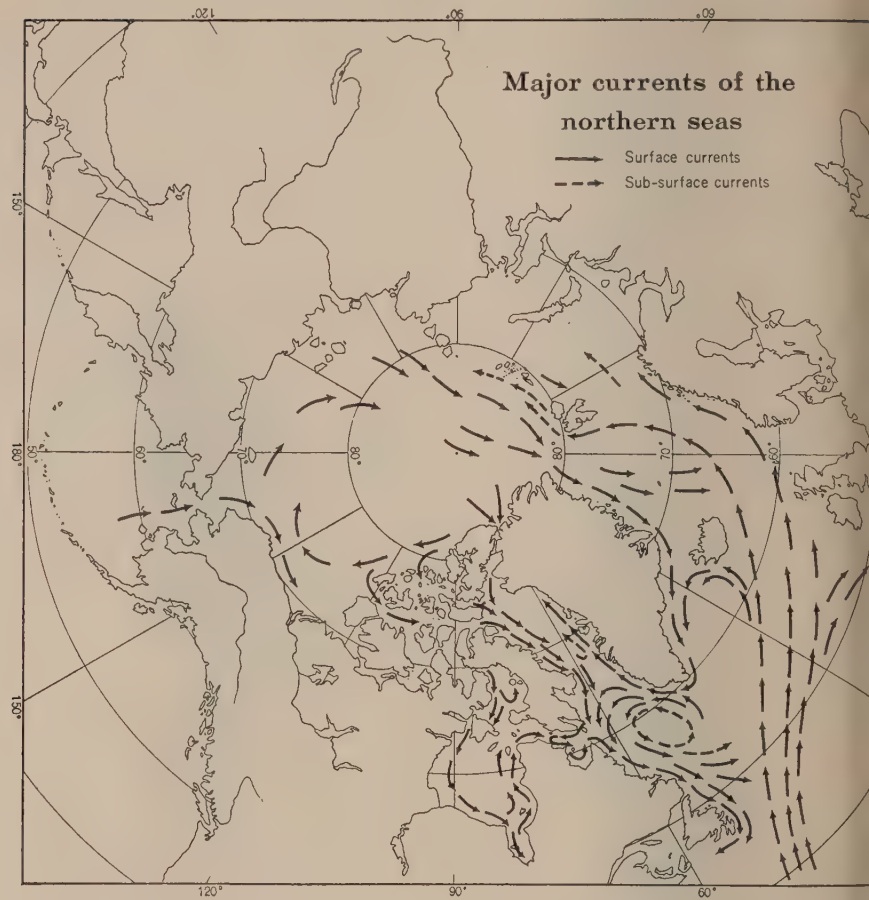


Fig. 3. Major currents of the northern seas. All details, lesser eddies etc., omitted.

growth rates[1]), which is otherwise of high production potential in suc properties as gases held in solution, nutrient salts, and high viscosity; bu this has still to be demonstrated. It has also been suggested that the presume high concentration of polymerized water molecules (trihydrol or highe polymer) in water recently melted from ice may have a beneficial effec upon the growth and division of plant cells, as has been demonstrated experi mentally. So far no method of measuring the concentration of specific wate polymers has been devised.

[1]It has been demonstrated that the growth rates of the larvae of certain bottom-livin forms in the arctic and subarctic are in fact no lower than in similar species in warme water, indicating presumably a genetically established regulating mechanism, but for th mass of the zooplankton, and for the phytoplankton, there is as yet no evidence of thi In fact, the much larger generation time in colder water in the holoplanktonic animal indicates a greatly reduced rate of growth. For the pelagic larvae of benthonic speci there are other pressing considerations which favour the selection of the higher growt rates, and which do not apply to the holoplanktonic forms.

There is another possibility in this matter of subarctic production which ıires testing, namely that the high production is caused entirely by up-ling of water from lower layers, laden with plant nutrients, at all times of r. Thus the underlying cause of the high production in the Icelandic ers, and in the vicinity of the Faeroes and northern Scotland is, on this v, the presence of the submarine ridge (Wyville Thompson ridge), running n Scotland to the Faeroes, and extending from there to Iceland and east enland, causing upwelling of Atlantic water. The ridge between Holsteins-g and southeast Baffin Island is supposed to play the same part in southwest enland. High production in the subarctic belt is thus looked upon as ctly comparable to the high production along the west African coast and west coast of South America, although the types of water upwelling are kedly different. In the latter two regions it is cold antarctic water which ıes to the surface, whereas any upwelling in the Iceland–Scotland area must f Atlantic water. Again, it may be that the mixture of polar and non-polar er causes general instability, favouring vertical exchange of water, and that is the important thing in determining subarctic production. It is of course r that upwelling, wherever it occurs, will normally increase production, t does everywhere in the usual annual succession of events. But it is still btful whether upwelling alone can explain the high subarctic production; significant that wherever arctic water meets boreal water, the production up. Moreover, it is by no means demonstrated that instability in sub-ic waters is the rule; there is high stability, for instance, in the west Green-l coastal current in summer.

Quite apart from further hydrographic work designed to show the stability nstability of subarctic waters, and the extent of upwelling, the measurement he phosphate and nitrate concentrations in both arctic and subarctic water uld go far towards elucidating this interesting matter, the discussion of ch dates as far back as Nansen (1902) and Gran (1902). The problem attacked by Braarud (1935) in Denmark Strait and the east Greenland rent, but it is not yet quite clear to what extent the supply of plant nutrients he surface layers is exhausted during the phytoplankton bloom, and how ı it is replaced. It is quite possible that the phosphate is not exhausted he arctic water in the spring, and that the arctic water may always have gnificant surplus of phosphate and nitrate to contribute to the subarctic, ı in summer.[1] The Russian Papanin expedition of 1937 found that although phytoplankton growth in the Arctic Ocean in July was poor, there was siderable flowering in August, by which time the snow cover had melted the penetration of light became possible. The presence of considerable ntities of phytoplankton beneath the ice in summer is also recorded from ıt Barrow (MacGinitie, 1949, personal communication). If the use of the ıt nutrients occurs so late in the season in the Arctic Ocean, it may well

[1] Measurements of phosphate by the *Dana* expeditions of recent years have shown low es. down to zero at the surface in July, in east Greenland. Measurements made by the *mus* expedition, however, in Cumberland Sound, Baffin Island, show somewhat higher es. and the *Godthaab* results were variable. The question is by no means settled.

follow that the outflow of nutrients in the east Greenland current and through the Canadian Archipelago in the spring is quite large.

The measurement of the amount of plankton can be done in several ways. The number of plant cells can be counted directly from samples collected in water samplers and preserved in weak formalin, a method which was used by Gran (1929) and by Braarud (1935), and which is at present being employed by Grøntved (1953, personal communication) on samples from west Greenland, with good results. The zooplankton, excluding the largest members, is measured by the use of vertical nets, or by quantitative mechanical samplers. Both these methods measure the "standing crop", or concentration of organisms at a given time, and they are reliable if enough samples are taken. Chemical methods, measuring the consumption or production of a given element or metabolism, provide an estimate of the rate of production; a recent innovation in this field is the Carbon-14 method developed by Steemann Nielsen (1952) and used on the *Galathea* expedition. All these methods should be applied to the North American Arctic and Subarctic.

There are particular areas where such study of the plankton production would be of special interest, such as Hudson Bay, the Arctic Ocean itself, and the Beaufort Sea. The latter, although strictly speaking a part of the Arctic Ocean, is nevertheless clearly influenced by non-arctic water from the Bering Sea. Hudson Bay is highly stratified in summer, and it has been supposed that the apparent low production of the Bay (which still has to be confirmed) is caused by the lack of proper vertical exchange of water during the winter. There are thus two points to be cleared up in Hudson Bay: the actual level of production of living matter, and the winter hydrographic regime. The latter can of course only be done by working stations through the ice, a technique which has already been tried out on several occasions: by the Danish Three Years expedition in east Greenland (1931–4), by the Papanin expedition in 1937, by Digby at Scoresby Sund, and by Nutt in the Goose Bay region in 1952. A technique of through-the-ice work is described and illustrated in Thorson's (1946) most useful paper on future work in arctic animal ecology.

The plankton production in the Arctic Ocean itself has been a matter of contention for many years, but it has never yet been measured. Nansen, after the famous *Fram* expedition of 1893–6, concluded that the Arctic Ocean was a barren area, because his plankton nets caught little plankton and the seal population seemed very low. Stefansson, on the other hand, having lived on seal during a prolonged trek across the polar ice during the Canadian Arctic expedition of 1913–8, obtained a quite different impression, and reported moreover, the abundance of so-called "shrimps" (possibly a pelagic amphipod) in the surface water between the ice floes. The collections of the Russian Papanin expedition of 1937 apparently confirmed Stefansson's conclusion rather than Nansen's, although the final plankton results do not seem to have appeared yet. Clearly this situation calls for decisive study, and the only way to do it is to maintain regular quantitative plankton collections all year round at one station, chosen for ease of access and depth of water. Probably the coast of northern Ellesmere Island, or of Greenland, offers the best conditions

penetration of light at all seasons of the year, and the oxygen and sphate concentrations, should of course be measured at the same time. Before leaving the subject of production, mention should be made (1) of necessity for study of winter as well as summer conditions in all phases, h in those areas normally frozen over, and in the ice-free subarctic regions outhwest Greenland, and (2) of the need for bacterial studies in northern , in order to establish the rate of bacterial mineralization of organic detritus.

Plankton biology in general

There are other facets of plankton biology in cold waters which offer iable returns for research, but which can be mentioned here only in sum-ized form:

Vertical diurnal migration of the plankton, a normal phenomenon all over world and largely dependent upon changes in illumination, was observed Svalbard waters, latitude 80°, in 1893 by Walther, even in the height of mer when the sun was well above the horizon at midnight. Walther was prised to find this phenomenon so far north in summer, but Russell (1927) since pointed out that the illumination which is able to penetrate the face at that latitude in June, at midnight, is very much less, midnight sun no midnight sun, than the penetration at noon. Later, however, Bogorov 946) published his observations in the Barents Sea, in which he found no dence of vertical migration during the height of summer. Clearly this oblem needs further research.

Cold-water plankton is remarkable for the large size attained by the ividuals, when compared with the same or closely related species in tem-ate or warmer waters. It has been assumed that the effect of the low mperature on the development of the gonads is one important factor: "De-ed sexual maturity, which favors growth in size, appears to be directly pendent on retardation of growth at lower temperatures, and this is a mmon characteristic of northern marine creatures" (Hesse, Allee, and midt, 1937, p. 159). It is not yet clear, however, why the gonadial growth es not maintain the same rate, relative to somatic growth, as in warmer ter. It may be that so much energy is required to offset the very low vironmental temperatures that the gonads are penalized in favour of the neral metabolism. Large size is an advantage at low environmental temper-res, for poikilotherms as for homoiotherms, but in poikilotherms it requires onger life to achieve it (relative to the size of the species), because growth es are controlled by the environment (see footnote p. 78); the adjustment the gonadial and somatic growth rates may therefore be established in the reditary mechanism of the species, and may not be simply and directly ntrolled by the external temperature. At all events, in order to throw ht on this perennially puzzling matter, an investigation of the metabolism arctic plankton animals is needed. The measurement of the oxygen require-nts of arctic plankton could be done quite simply in an adequately equipped p's laboratory, but more simply in a shore station. The results would

dovetail usefully with the work of Thorson (1936), who studied the oxygen metabolism of shallow-water benthonic forms, mostly molluscs, in northeast Greenland, and found that the metabolic rate was approximately the same as in closely related temperate (Danish) species and in tropical species, each group being measured at their normal environmental temperatures. Measured at the same temperature, the arctic forms showed a considerably higher metabolic rate. The whole matter of body size and metabolic rate has recently been reviewed, with considerable new experimental work, by Zeuthen (1947) and a theoretical development of the question has been published by Hemmingsen (1950).

(3) Thorson (1946, p. 25) mentions the food of zooplankton in the north as requiring research. To quote one point from his paper: "Ussing [1938] is of opinion that in winter most copepods [in east Greenland] are able to live on the food obtained in summer (stored as oil drops). Place, therefore, such winter-copepods in sterile sea-water to have this problem cleared up." This work, together with the metabolic study already mentioned and other research discussed below, needs wintering parties with laboratories equipped with constant temperature aquaria, filtering devices, and so on. Laboratories aboard research vessels, even small vessels, should also be similarly equipped if possible.

(4) Breeding cycles of planktonic animals, the nature of which is fundamental to the production of the standing crop each year, require a great deal of study, and for best results also call for winter as well as summer work. The fact that interesting complications arise in the breeding cycles of certain zooplankters in the north has already been demonstrated by Dunbar (1941). Generation time in certain copepods has been studied by Ussing (1938), and the bimodal size-distributions in copepods found in northern waters by Ussing and by Jespersen (1934) are also involved in this matter of breeding cycles. The suggestion of Ussing that the surface water of fjords, which is warmer in summer time and which has been called "fjord water" by the Danish workers, is important and perhaps essential to the survival of arctic copepods requires testing.

Benthonic and littoral fauna

Many benthonic and littoral animals are sessile, and all of them, except the fishes, are limited in powers of locomotion and dispersal. Most of them, moreover, are restricted in their distribution with respect to depth. These circumstances make it less simple to follow the arctic–subarctic pattern of distribution in the benthos and littoral than in the plankton and nekton. Large scale changes in the position and extent of the subarctic marine belt will of course result in extinctions of sessile populations and their replacement by others, but at any time during this climatic cycle there will always be seasonal differences in temperature in the upper 30–50 metres of water, which will greatly affect the distribution and living conditions of these forms. This has been pointed out and developed in a very interesting manner by Lemche (1941) for the opisthobranch gastropods of east Greenland. Forms of more southern affinities are found in northeast Greenland in the upper waters only, where

roduction can take place at less rigorous temperatures in the summer. ow this zone there is a population of arctic forms which live at the lower ıperatures all year round. Consequently, if the distribution of the two ups are placed on the same map without taking depth into account, they found to coincide almost exactly in east Greenland. This of course is te misleading, and emphasizes the fact that for the division of the benthonic na into arctic and subarctic regions it is essential to allow for this differ- ıation within the upper water layers. (The criterion employed, described ve, deals with the upper 200–300 metres of water, which is the approximate th of the arctic water layer in the Arctic Ocean; below this the depth tor applies also, naturally, to the plankton). So far, no work of this sort been done on the North American Arctic shallow-water benthos.

The distinction between the two groups just mentioned lies in their repro- tive physiology, and there is no doubt that the most promising lines of earch in this ecological division lie in the elucidation of the reproductive uirements and limitations. Dr. Gunnar Thorson, of the University of penhagen, has made notable advances in this field, and since he has already iewed the whole subject on a global scale (Thorson, 1950; 1951), and also ıblished the study in arctic waters (Thorson, 1936) and indicated the points ich require research in the immediate future (Thorson, 1946), it is not posed to deal with this subject here. It must be enough to point out that aluable contribution to the whole pattern of benthonic reproductive habits, ich are of great interest, would be made by applying Thorson's methods the North American fauna, particularly as regards the presence or absence d length) of the larval life. There is also much work to be done on the sity of the benthonic fauna, by the use of bottom samplers, along the lines Vibe's (1939) work in the Thule and Upernavik districts.

The term "littoral" is used here as coextensive with "intertidal", and thus in the sense advocated by Hesse, Allee, and Schmidt (1937). The littoral na has special conditions to face, in which the atmospheric climate must v an important part. It was upon the marine climate, however, not the ospheric climate, that the study of Madsen (1936; 1940) put the emphasis ossibly determining the distribution of northern littoral faunas. His work gested that the littoral fauna in large part disappeared north of a point ich was determined by the nature of the water, possibly by the presence or ence of Atlantic water on the coast. This point would thus coincide with boundary between the arctic and subarctic regions as defined in this paper, hence the nature of the littoral fauna might serve as an added indicator of drographic conditions. Before this possibility can be developed, however, reat deal of littoral collecting is necessary, especially in the North American arctic.

Apart from such zoogeographical considerations, the littoral fauna of the thern seas calls for investigation of breeding seasons and breeding cycles at erent levels on the beach, and of the conditions of survival during the ter, on all of which points our knowledge is extremely poor. The biology

of such abundant forms as the amphipod crustacean *Gammarus* (several species), the barnacle *Balanus balanoides*, and the snail *Littorina saxatilis*, for instance, has scarcely been studied at all on arctic and subarctic shores; and almost nothing is known of the northern littoral microfauna.

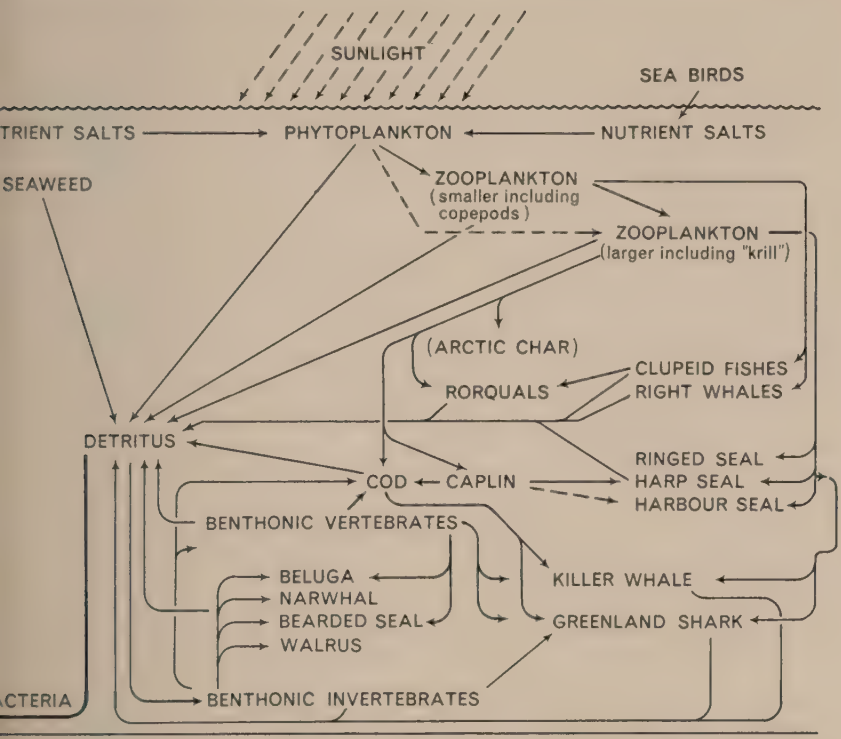
Nekton (fishes and marine mammals)

It is in the study of the macrofaunal elements of the northern seas that we come into immediate contact with the economy of the Eskimo, and it is here that investigations intended to develop new resources, or to conserve the old, become of immediate value. They are not on that account necessarily the most important in the long run, but they appeal to the general public, and hence reach more easily for the public purse-strings than the more obscure scientific projects can hope to do.

In true arctic waters, that is, inside the arctic zone as here defined, fishes are not abundant, and the nektonic constituent in the biomass is dominated by the mammals; in the subarctic waters, fishes make up a very important part of the total fauna, and the mammals are not dominant. This interesting fact which has as a corollary the direct dependence of the mammals, in the arctic zone, upon the macroplankton (invertebrate) instead of on the fish, has never been explained, nor has there been any attempt to throw light upon it experimentally. Speculation upon it leads to a consideration of the glacial history of the northern waters, and of the time-scale in the evolution of fishes, and although the problem of the glacial history can be attacked in various ways through the study of northern marine ecology today, it is not the purpose of this paper to develop this line of thought. It has been touched upon in another paper (Dunbar, 1951b).

The problem can also be attacked, more directly, by the study of the metabolism of arctic fishes at the temperatures at which they live, and of the general relation which their reproduction and development bear to temperature. It should be emphasized that the poverty of the fish fauna, in terms of number of fish species, is not itself surprising—it is part of the general picture of few species of most groups in arctic water.[1] What has to be explained is why no single species has been able to achieve a dominant or even an important position in the total fauna, in contrast to other poikilotherms, all of them invertebrates many of which are extremely abundant in arctic water, such as certain amphipods, copepods, and molluscs.

[1]A recent study (Thorson, 1951) has thrown a new light on the matter of species numbers in the marine environment of the arctic, temperate, and tropical regions. For intertidal and shallow-water invertebrates, it is the "epifaunal" species which increase greatly in numbers toward the tropics, the "epifauna" including all dwellers upon surfaces of various substrates, such as rock, stones, coral reefs, and seaweed, whereas numbers of species in the "infauna", mainly burrowing forms in the large uniform environment of sandy and muddy bottoms, are approximately the same in comparable environments in all three major zones, tropics to arctic. In the light of this, the poverty of fish species (and also of holoplanktonic species) in the arctic water appears to be a breach of the rule, for ecologically the fishes, especially the pelagic fishes, must be compared with the benthonic and littoral "infauna", for which the environment is constant over large areas and not broken up into a multitude of small habitats as in the epifaunal environments.



4. The biological cycle in the arctic and subarctic marine zones, somewhat simplified. prey-predator system illustrated in the right-hand three-quarters of the figure ends y in the production of organic detritus, which is decomposed by the bacterial action ly on the sea-floor in moderate depths. The resulting supply of inorganic plant ents (nitrates, phosphates) is returned to the surface by vertical water exchange in utumn and winter, and is thus available for the regeneration of the phytoplankton population in the springtime conditions of increasing sunlight.

The poverty of the fish fauna in arctic water is particularly remarkable he pelagial, as opposed to the littoral and benthal, regions. The polar cod, *ogadus saida*, although frequently referred to as a pelagic form because often seen among ice floes, is in fact much more commonly found close he bottom in fairly shallow water; and the arctic char, *Salvelinus alpinus*, ough in part a planktonic feeder during its short annual stay in salt water, ot be considered a true pelagic species on that account. The shallow r benthos includes a few families of fishes which are widespread although here very abundant. The young of these benthal forms, Cottids, Liparids, nids, Gadids, etc., are often taken in plankton nets, especially at night, and probable that much more could be learned about their abundance and habits by the use of large (two-metre) stramin nets, and other types of l-mesh mid-water trawls. Pelagic young fish escape, for the most part, the ordinary plankton nets. The same is true of the largest pelagic

crustacea, such as the Hyperiid amphipods and the Euphausids which, like the young fish, lie on the border-line between the plankton and the nekton and which can be collected adequately only with appropriate mid-water trawls.

The subarctic fisheries must be left out of the present paper; they are an extremely large subject in themselves. Moreover, they are being studied and developed constantly, in such areas as west Greenland, Spitsbergen, and the Norwegian, Barents, and Kara seas. There is room for considerable biological work on the economic fishes of the Labrador coast, however, and the possibilities of the Beaufort Sea have yet to be investigated fully. At the northern edge of the subarctic water, and also beyond it, there is a need for experimental fishing for such forms as the arctic halibut, *Reinhardtius hippoglossoides* and the Greenland shark, *Somniosus microcephalus*, in Baffin Island waters and northward. In the Burwell area of Ungava Bay the *Calanus* expedition recorded the young of the arctic halibut, but the adults have not yet been taken.

In terms of man's immediate interests, there is an urgency about the scientific study of the arctic and subarctic marine mammals which does not apply to any other marine problem discussed here. The northern sea mammals have been hunted by Eskimo and by Europeans for centuries; the European killing has been for a shorter time, but has been very much more destructive. The Eskimo, by themselves and uninfluenced by Europeans, had struck a natural balance between themselves and their sea mammal resources. They were themselves part of an established ecological system. The commercial whalers and sealers, on the other hand, came from another system upon which they were dependent, and their activities among the northern sea mammals may rightly be termed an invasion. As might be expected, the species which they prized most, the Greenland whale or bowhead, was soon brought to the verge of extinction, and the introduction of the rifle to the Eskimo, by both whalers and traders, is now doing considerable damage to the seal populations. Whatever recriminations may be made about these two facts (the one is historical, the other is now much more than a simple zoological problem), they have left problems which the zoologist can certainly tackle.

It is probably true that all marine mammal species in the north, at one or more points of their range, are now seriously reduced in numbers. There may be exceptions to this, for instance the white whale and the narwhal, which possibly are holding their own, but in general the marine mammal populations have been declining, and in a belated awareness of this, we are faced with the fact of our almost complete ignorance of the most elementary matters of their life histories. The cases of the Greenland whale and the walrus are particularly clear. Since the almost complete extinction of the bowhead before the First World War, it has been given protection, and there are signs now that the population has been very slowly increasing; for the present there is little to do about it except to leave it in peace, and to keep records of its recovery. But the walrus is another matter; there is clear evidence that the walrus was once much more widespread than it is at present, and it is improbable that this retreat has been caused entirely by changes in climate during the last few

red years, although that may have had something to do with it. The is has been the object of commercial hunting for several centuries, and still occasionally killed in numbers by sealing vessels. It is also hunted skimo armed with rifles, some at least of whom seem to have forgotten fathers' hunting wisdom, so that there is much waste, especially in summer, n would not have occurred in earlier times, and without the rifle. The is true of other Pinnipedia in the north. The sinking during the summer ng, caused by shooting the animals from a distance, very often without ate means of retrieving them, accounts for the wastage of a ridiculously proportion of the seal and walrus. It would be a mistake to think that natter does not come into the business of the marine biologist. The o is part of the marine system, just as the whaler is, and his activities are important zoologically. In this connection, the designing and introduc- of a good, inexpensive shoulder harpoon gun would be helpful.

We have to make a study of the life histories of the marine animals, ning from almost nothing, in order to discover where we may apply rvation measures. A little has been published on the walrus, from Alaska ins, 1940) and from northwest Greenland (Vibe, 1950), but for the rest ave only scattered observations published in odd corners of expedition ts, popular books, or filed in manuscript in Government offices. There excellent account of the harp seal (*Phoca groenlandica*) of the White rea by Sivertsen (1941), and Fisher (1952) is conducting a thorough of the harp seal on its Gulf of St. Lawrence breeding ground, sponsored e Fisheries Research Board of Canada. The harp seal, like the hooded *Cystophora cristata*), is a migrant species, spending the summer in the . Those which breed in the Newfoundland and St. Lawrence area move st Greenland and Baffin Bay in the spring, and they are fairly common gava Bay and along the eastern and northern coasts of Baffin Island. It this northern part of the harp seal range that we need information on dance, food habits, and migration. It is possible that some of the adolescent emain in the north during the winter; if so, it is important that we have estimate of the numbers involved, in order that population studies done r south, in the breeding areas, may take this into account.

For those sea mammals that breed in the north—walrus, ringed seal (*Phoca da*), bearded seal (*Erignathus barbatus*), and some of the harbour seal lation (*Phoca vitulina*), also the beluga or white whale and the narwhal, gram of research should include the following: (1) A census done by ing breeding colonies, summer schools, hunting kills, and by running s from ships in transit, all of which must be kept up through the years. The collection of reproductive tracts, stomach contents, and parasites, in ient numbers to give good material for laboratory study. (3) The tion of teeth and possibly certain bones (bacula, for instance) for ageing ses, so that the age composition of the population may be determined; he discovery of good methods of ageing in general (the use of teeth is new for seal and walrus, and there may be other means). (4) The of migrations, especially winter distribution. It is not known, for

instance, whether the walrus of Hudson Bay remain within the Bay during the winter or not, nor is it known which group of walrus visits Akpatok Island in early July each year. Something of the winter distribution could be discovered by air surveys, but the only final way of establishing migration habits is by marking the animals at the breeding grounds. This presents quite a problem, especially in species as large and formidable as the walrus, or as elusive as the beluga, and one of the most important problems to be solved is just how to mark them.

Systematic and zoogeographic studies

The fauna of the North American Arctic and Subarctic waters and coasts (except those of Greenland) is still poorly known. The large gaps in the distribution maps are being filled in, but even when the work of the *Calanus* and *Blue Dolphin* expeditions, and of the Point Barrow Laboratory, is published, there will still be a great deal of faunistic work to do, particularly in the central arctic section, and in the Beaufort Sea. The present signs are that when these gaps are filled in, the results will be very interesting. Ekman (1953, p. 159) has collected evidence to show that "a considerable part of the North Atlantic boreal fauna and the Polar Sea arctic fauna is derived from the North Pacific", and although the evidence is of the equivocal sort that zoogeography is often forced to use for lack of anything better, it is also the sort that is accepted by most zoogeographers. The shelf fauna of the North Pacific contains many more species and genera than are to be found on the North Atlantic shelf, and it is only in the Pacific region that endemic families are found. Given certain premises (which are not quite argument-proof) this is evidence for the dispersal of the fauna from the Pacific to the Atlantic. However that may be, there is good indication that there has been a dispersal from the North Pacific or Bering Sea area eastward to the Canadian Eastern Arctic, and also westward to the waters of the Siberian shelf, which has hitherto left the coasts of Greenland and of northwest Europe almost untouched. This is at present represented by the land-locked seal of Seal Lakes in the Ungava Peninsula, by certain of the fishes in Hudson Bay and Ungava Bay and by several amphipod species; and the full study of the Eastern Arctic fauna will no doubt bring many more such examples to light. Such distributions are doubtless a legacy from early postglacial times, and the whole study of arctic zoogeography has an important bearing on the glacial and postglacial history of the North American Arctic.

Within the arctic zone, the phenomenon of circumpolarity appears to be fairly common, although the addition of the North American sector to the picture may well change our ideas in this as in other aspects of northern marine distribution. It may well be that there are variations within circumpolar species, which will be significant of isolation within the circumpolar area, especially in the littoral and benthonic species; and even for holoplanktonic forms there is the possibility of isolation by current systems. In the marine subarctic, the true monotypic circumpolar species is the exception

:r than the rule, and the investigation of the extent and quality of variation in subarctic genera is a matter of great interest to the student of evolution, will be much extended by the filling in of the North American gap in our wledge.

As for the fauna of the deep basins, there can be little doubt that even ıe regions where most exploration has been made, as in the Greenland Norwegian seas, there is still much to be added. In Baffin Bay our present wledge is based almost entirely on the results of one short expedition, the *thaab* expedition of 1928. At the present stage of the study there appears e a large number of species common to all the arctic basins (Arctic Ocean, wegian and Greenland seas, and Baffin Bay), a fact which may have esting implications concerning the recent history of those depths. Before firm conclusions can be drawn, however, there is much deep-water ging and bottom sampling to be done.

There are many groups, which cannot be mentioned in detail here, whose ematics are in a somewhat chaotic state. For some of these, such as the id and Liparid fishes, we need embryological studies in order to untangle pattern of relationship, and for others, such as several amphipod families, ıeed large collections from the whole circumpolar field.

Finally, since zoogeography is a study of a dynamic, not a static, pheno- on, and since changes in the distribution of marine animals can be of sive economic importance, it is necessary to keep routine observations g every year, or at regular intervals, not only upon the fauna itself, but ı the hydrographic conditions which, more than anything else, determine composition of the fauna. Changes in the marine climate have not been ed in this paper, partly because of lack of space, partly because their ence and their overwhelming importance are now well established, and continued study of them may be taken for granted.

The author wishes to acknowledge his indebtedness to Dr. Gunnar rson of the University of Copenhagen for reading the manuscript of this r, and for valuable suggestions.

References

rov, B. G. 1946. "Peculiarities of diurnal vertical migrations of zooplankton in polar s". *J. Marine Res.* Vol. 6, No. 1, pp. 25–32.

ud, T. 1935. 'The phytoplankton and its conditions of growth.' *Hvalrådets Skrifter*, . 10, 173 pp.

ns, G. 1940. "Habits of the Pacific walrus (*Odobenus divergens*)." *J. Mammal.* Vol. pp. 138–44.

ar, M. J. 1941. "The breeding cycle in *Sagitta elegans arctica* Aurivillius." *Can. J. s.* Sec. D, Vol. 19, No. 9, pp. 258–66.

1951a. 'Eastern Arctic waters.' *Fish. Res. Bd. Can. Bull.* No. 88, 131 pp.

1951b. "Resources of arctic and subarctic seas." *Trans. Roy. Soc. Can.* l. 45, Ser. III, Sect. V, pp. 61–7.

an, S. 1953. 'Zoogeography of the sea.' London: Sidgwick and Jackson, 417 pp.

r, H. D. 1952. "Harp seals of the northwest Atlantic." *Fish. Res. Bd. Can. Atl. l. Sta., Circular*, Gen. Ser. No. 20, 4 pp.

Gran, H. H. 1902. 'Das Plankton des norwegischen Nordmeeres.' *Rep. on Norw. Fishery- and Marine-Investigations*, Vol. 2, No. 5, 222 pp.

1929. 'Quantitative plankton investigations carried out during the expedition with the "Michael Sars", July-Sept. 1924.' *Cons. Perm., Rapp. et Proc.-Verb.* Vol. 56, 50 pp.

Hemmingsen, A. M. 1950. "The relation of standard (basal) energy metabolism to total fresh weight of living organisms." *Rep. Steno Memorial Hospital and the Nordisk Insulinlaboratorium*, Vol. 4, pp. 1–58.

Hesse, R., W. C. Allee, and K. P. Schmidt. 1937. 'Ecological animal geography.' New York: John Wiley, 597 pp.

Jespersen, P. 1934. 'Copepoda, the Godthaab Expedition 1928.' *Medd. om Grønl.* Vol. 79, No. 10, 166 pp.

Lemche, H. 1941. 'The zoology of east Greenland. Gastropoda Opisthobranchiata.' *Medd. om Grønl.* Vol. 121, No. 7, 50 pp.

Madsen, H. 1936. 'Investigations on the shore fauna of east Greenland with a survey of the shores of other arctic regions.' *Medd. om Grønl.* Vol. 100, No. 8, 79 pp.

1940. 'A study of the littoral fauna of northwest Greenland.' *Medd. om Grønl.* Vol. 124, No. 3, 24 pp.

Nansen, F. 1902. 'The oceanography of the North Polar Basin.' *Norw. North Polar Exp. 1893–1896, Sci. Res.* Vol. 3, Pt. 9, 427 pp.

Russell, F. S. 1927. 'The vertical distribution of plankton in the sea.' *Biol. Rev.* Vol. 2, pp. 213–62.

Sivertsen, E. 1941. 'On the biology of the harp seal *Phoca groenlandica* Erxl.' *Hvalrådets Skrifter*, No. 26, 166 pp.

Steemann Nielsen, E. 1952. "The use of radio-active carbon (C-14) for measuring organic production in the sea." *J. du Conseil*, Vol. 18, No. 2, pp. 117–40.

Thorson, G. 1936. 'The larval development, growth, and metabolism of arctic marine bottom invertebrates compared with those of other seas.' *Medd. om Grønl.* Vol. 100, No. 6, 155 pp.

1946. 'Technique and future work in arctic animal ecology.' *Medd. om Grønl.* Vol. 144, No. 4, 40 pp.

1950. "Reproductive and larval ecology of marine bottom invertebrates." *Biol. Rev.* Vol. 25, pp. 1–45.

1951. "Zur jetzigen Lage der marinen Bodentier-Okologie." *Verhandl. d. Deutschen Zool. Gesellsch. in Wilhelmshaven*, pp. 276–327.

Ussing, H. H. 1938. 'The biology of some important plankton animals in the fjords of east Greenland.' *Medd. om Grønl.* Vol. 100, No. 7, 108 pp.

Vibe, C. 1939. 'Preliminary investigations on shallow water animal communities in the Upernavik- and Thule-districts (northwest Greenland).' *Medd. om Grønl.* Vol. 124, No. 2, 42 pp.

1950. 'The marine mammals.' *Medd. om Grønl.* Vol. 150, No. 6, 115 pp.

Zeuthen, E. 1947. 'Body size and metabolic rate in the animal kingdom, with special regard to the marine micro-fauna.' *Comptes Rendus d. Trav. du Laboratoire Carlsberg*, Sér. Chim. Vol. 26, No. 3, 161 pp.

362

BRITISH COLUMBIA DEPARTMENT OF FISHERIES, 1953

Contributions to the Life-history of the Sockeye Salmon

[PAPER 38.]

BY

D. R. FOSKETT, B.A., M.A.,
PACIFIC BIOLOGICAL STATION, NANAIMO, B.C.

[REPRINTED WITHOUT CHANGE OF PAGING FROM THE REPORT OF THE BRITISH COLUMBIA DEPARTMENT OF FISHERIES, 1952.]

APPENDICES

CONTRIBUTIONS TO THE LIFE-HISTORY OF THE SOCKEYE SALMON (No. 38)

By D. R. Foskett, B.A., M.A., Pacific Biological Station, Nanaimo, B.C.

INTRODUCTION

The more important sockeye-salmon runs in British Columbia are sampled each year to study the distribution of ages and sexes in the commercial catch. Length and weight characteristics of each sex and age groups contributing to the catches are also recorded. This is the thirty-eighth report since 1914 recording, by major fishing areas, the composition of the landings and commenting on the spawning escapements.

DESIGNATION OF AGE-GROUPS AND TREATMENT OF DATA

Two outstanding features in the life-history of the fish have been selected in designating the age-groups—namely, the age at maturity and the year of its life in which the fish migrated from fresh water. These are expressed symbolically by two numbers—one in large type, which indicates the age of maturity, and the other in small type, placed to the right and below, which signifies the year of life in which the fish left fresh water. The age-groups which are met most commonly are:—

3_1, 4_1—the "sea types" or fish which migrate seaward in their first year and mature in their third and fourth year respectively.

3_2—"the grilse," usually males, which migrate seaward in their second year and mature in their third year.

4_2, 5_2—fish which migrate seaward in their second year and mature in their fourth and fifth years respectively.

5_3, 6_3—fish which migrate seaward in their third year and mature in their fifth and sixth years respectively.

6_4, 7_4—fish which migrate seaward in their fourth year and mature in their sixth and seventh years respectively.

Fish were measured to the nearest quarter of an inch and averaged to the closest tenth of an inch. Most weights were recorded to tenths of a pound and so tabulated in quarter-pound groupings as to produce an even-pound and half-pound bias. This bias is especially evident for Smith Inlet, where much of the original data was recorded to the nearest half-pound.

1. THE NASS RIVER SOCKEYE RUN OF 1952

(1) General Characteristics

The pack of sockeye on the Nass River, 29,492 cases (Table I), was much better than in 1951 and decidedly above the average for the past ten years. The escapement was reported as satisfactory.

(2) Age-groups

The most prominent age-group in the 1952 Nass sockeye run was that of the 5_3's (46 per cent), with the 4_2 and 5_2 age-groups forming 28 and 19 per cent respectively (Table I). The 6_3 age-class formed 4 per cent of the sample. Three per cent of the sample was recorded as sea-run types, but there is some doubt concerning these interpretations.

(3) Lengths and Weights

The Nass River fish were very large, approaching in size those taken in 1951 (Tables IV and V). The average weight of fish in the samples was 6.4 pounds. This is the same value as that obtained from the statistics of the Federal Department of Fisheries.

(4) Distribution of Sexes

There was nothing unusual in the distribution of sexes in the Nass River sockeye (Table VI). The 5_2 and 6_3 age-groups, with 56 and 59 per cent males respectively, were furthest from the total sex ratio of the sample, which was 50:50.

2. THE SKEENA RIVER SOCKEYE RUN OF 1952

(1) General Characteristics

The 1952 Skeena River sockeye-pack (114,775 cases) was almost double that of 1951, and the fish were of approximately the same size as those of the 1951 run. The spawning runs were of average size, except in the Babine area, where a rock-slide in the Babine River caused a very large loss of spawners and probably reduced the effectiveness of thousands which did succeed in reaching the lake. Conditions for the survival of the eggs deposited appeared to be normal.

(2) Age-groups

In the Skeena River catch sample, 66 per cent were in the 4_2 age-group and 26 per cent were 5_2 age-class fish (Table VII). The only other groups present in important numbers were the 5_3 and 6_3 age-classes, forming 3 and 5 per cent of the sample respectively. The minor age-groups present and the numbers of fish in them may be found in Tables VIII and IX.

(3) Lengths and Weights

The 4_2, 5_2, and 6_3 age-groups were composed of relatively large fish for these groups (Tables X and XI). The 4_2 males exceeded in length and weight the records for the past ten years, and the 4_2 females equalled their records (Tables X and XI). The average weight of the fish in the sample was 5.8 pounds. The average weight of the catch, as calculated from the Federal Department of Fisheries statistics, was 6.0 pounds, showing acceptable agreement.

(4) Distribution of Sexes

As may be seen from Table XII, the sex ratio in the two main age-groups closely follows the pattern of the past ten years, while that of the whole sample is close to the theoretical 50:50 distribution, being 48 per cent males and 52 per cent females.

3. THE RIVERS INLET SOCKEYE RUN OF 1952

(1) General Characteristics

The Rivers Inlet sockeye-pack was 84,297½ cases in 1952 (Table XIII). The very heavy spawning escapement in the area was in part the result of the fishermen's strike which occurred just after the peak of the run, at a time when normally the catch would have been large.

(2) Age-groups

As usual, the 4_2 and 5_2 age-groups predominated in the 1952 Rivers Inlet salmon-catch sample, forming 41 and 58 per cent of the run respectively (Table XIII). A few 5_3 and 6_3 age-class fish were present and one fish in each of the 3_2 and 6_2 age-groups (Tables XIV and XV).

(3) Lengths and Weights

Both the 4_2 and 5_2 age-class salmon were large, the latter equalling or exceeding the averages recorded during the past ten years (Tables XVI and XVII). The average weight of the sample is 0.3 pound greater than that of the total catch, obtained by using the Federal Department of Fisheries statistics. The discrepancy is not great, but is probably real, and to be explained by the inclusion in the sample of a disproportionate number of fish caught near the head of the inlet. The average size of fish caught in that area is greater than the average size of fish caught near the mouth of the inlet.

(4) Distribution of Sexes

The distribution of sexes within the age-classes followed closely the pattern of the past ten years (Table XVIII). The general ratio of 44 males to 56 females was the same as in 1951.

(5) Spawning-ground Samples

In the Rivers Inlet area, sampling was extended to the spawning-grounds. With the assistance of Federal Fisheries Inspectors Houghton and White and the co-operation of their patrolmen, 838 fish were measured on the spawning-grounds. Of these, 539 were males and 299 females, giving a sex ratio of 64:36. Of the males, 108 were jacks (3-year-olds). Excluding them the sex ratio is 59:41. This value is in marked contrast to that obtained from the sample of the commercial catch. Degeneration of the scales takes place among ripening salmon, with the result that scales cannot be used for age determination. However, length-frequency diagrams, such as those shown in Fig. 1, give clear indication of the age distribution in the sample. Because of the development of secondary sexual characters, the distributions do not agree in detail with those obtained for samples from the fishery (Fig. 2), but the various groups are clearly distinguishable.

(6) Comparison of Samples from the Fishery and the Spawning-grounds

Figs. 3 and 4 compare the size distributions of sockeye in the catches and on the spawning-grounds. Immediately evident is the fact that the fishery makes no use of the jacks. It is also clear that the fishery heavily exploits the large 4_2 males and the small 5_2 males, making relatively little use of the smallest and largest fish. The larger 5_2 females are also used relatively little, although selection effects are less marked than among males.

The difference between fishery and spawning-ground length frequencies results from the greater effectiveness of each size of gill-net on fish of a certain size. This has not been made the subject of a thorough study, but preliminary observations show that the effect can be quite critical. In 1951 the average weight of sockeye caught by eight fishermen fishing in the lower part of the inlet with 5⅜-inch mesh nets was 6.3 pounds. This may be compared with the 6.8-pound average from landings by ten fishermen using 5½-inch mesh over the same period in the same area.

4. THE SMITH INLET SOCKEYE RUN OF 1952

(1) General Characteristics

The Smith Inlet sockeye-pack in 1952, 34,834 cases, was not as good as that of the past two years but was approximately the same as that of the cycle-year. The fish were, however, of good size, and the spawning run was excellent.

(2) Age-groups

As 91 per cent of the Smith Inlet sockeye sample was composed of 5_2 age-class fish (Table XIX), the catch was very uniform. The 4_2 age-class formed only 8 per cent of the sample, and the 5_3 group, 1 per cent. Two 6_2 age-class fish were present, and one

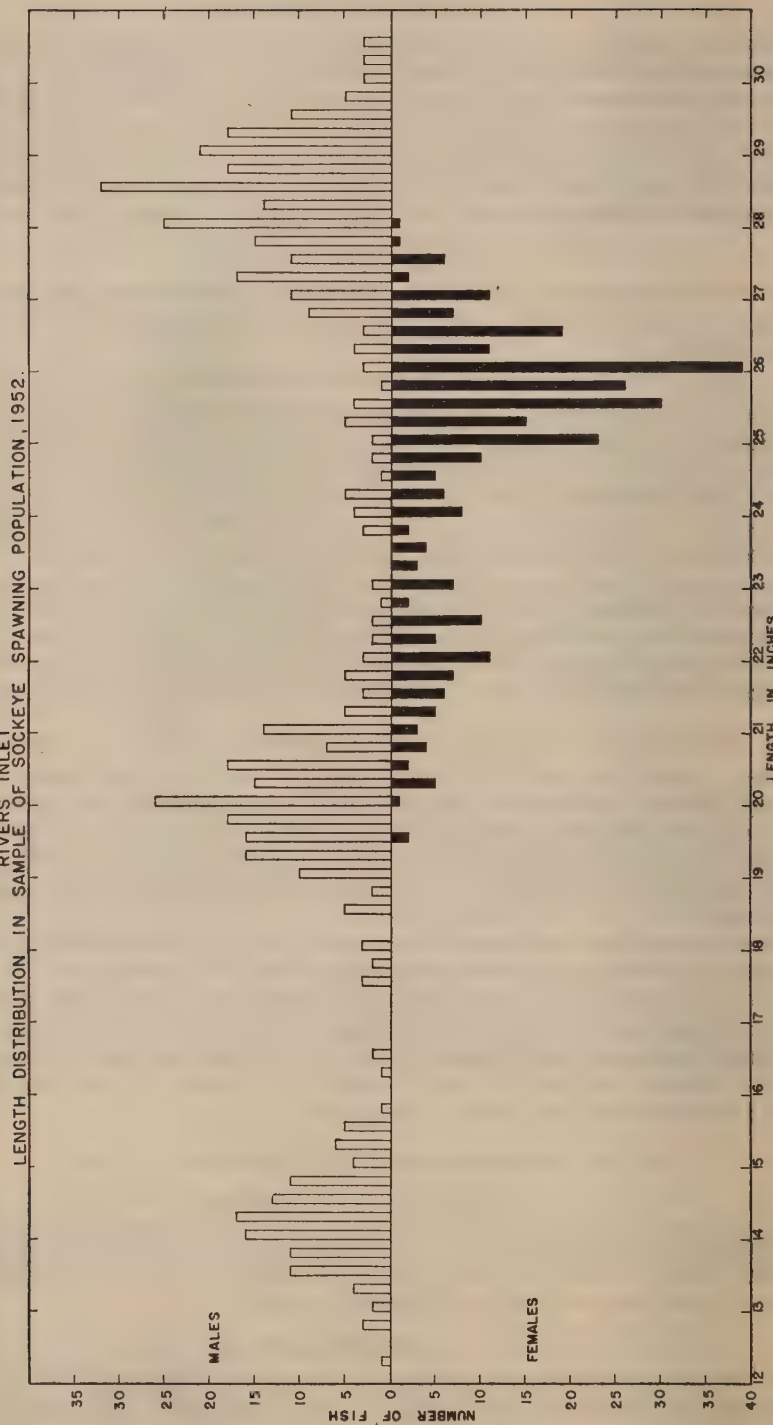
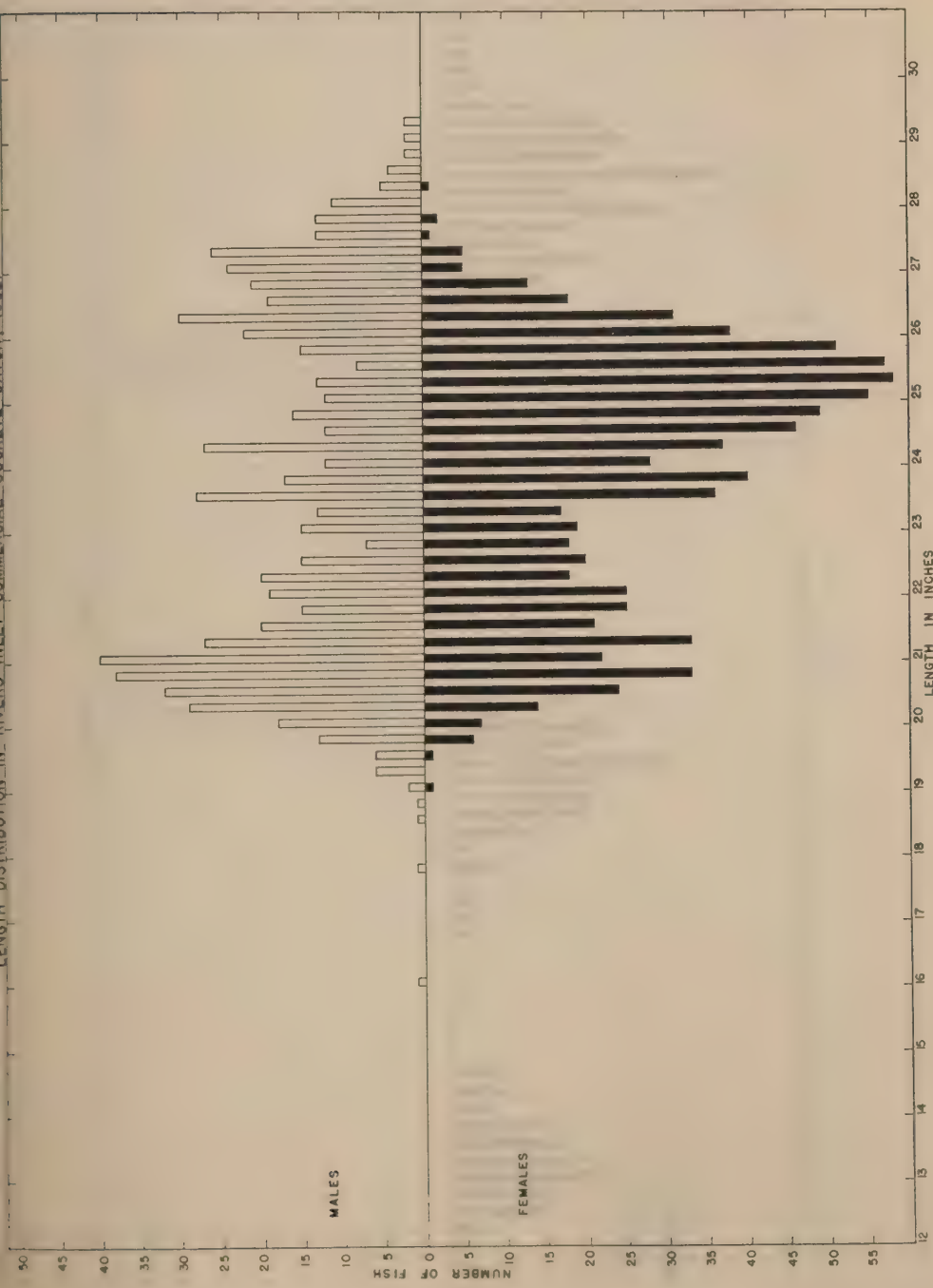


FIGURE 1.
LENGTH DISTRIBUTION IN SAMPLE OF SOCKEYE SPAWNING POPULATION, 1952.
RIVERS INLET


MALES
FEMALES
NUMBER OF FISH
LENGTH IN INCHES

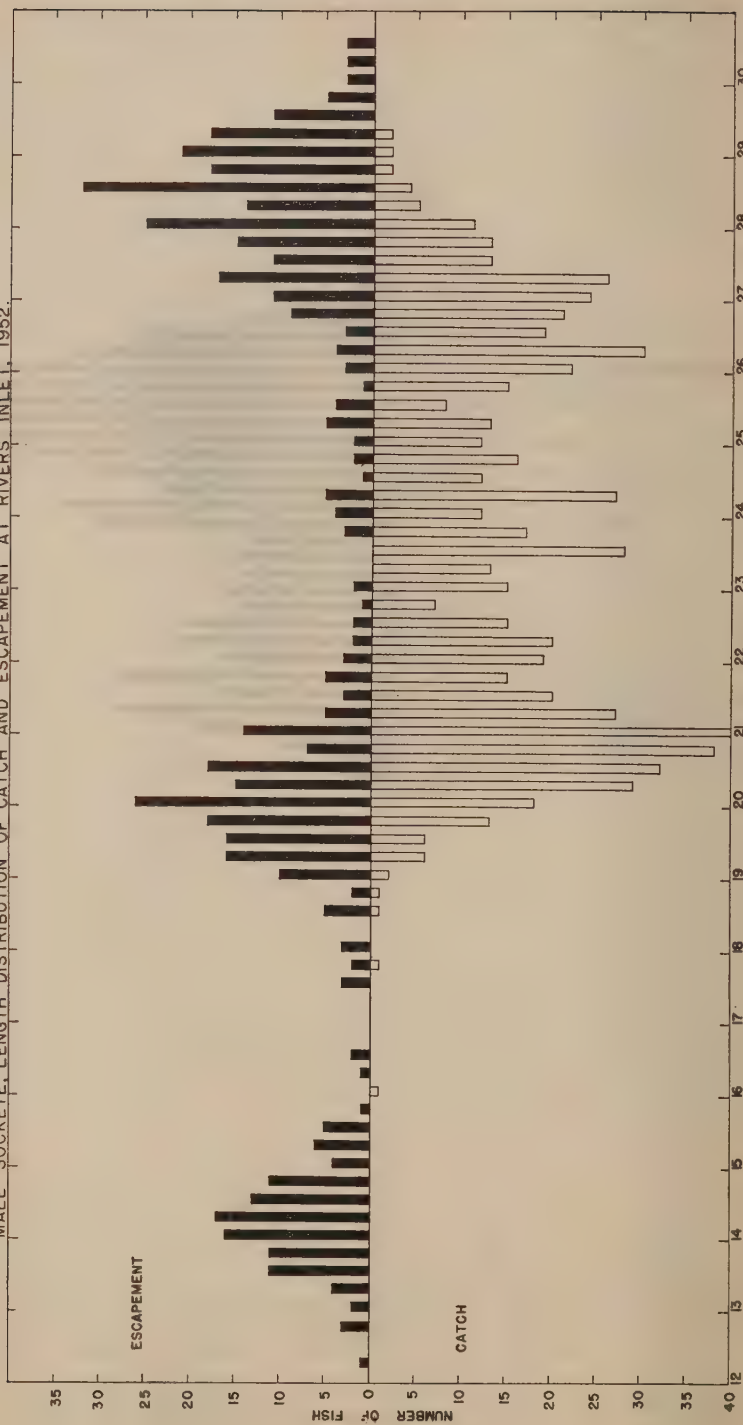


FIGURE 3.
MALE SOCKEYE, LENGTH DISTRIBUTION OF CATCH AND ESCAPEMENT AT RIVERS INLET, 1952.

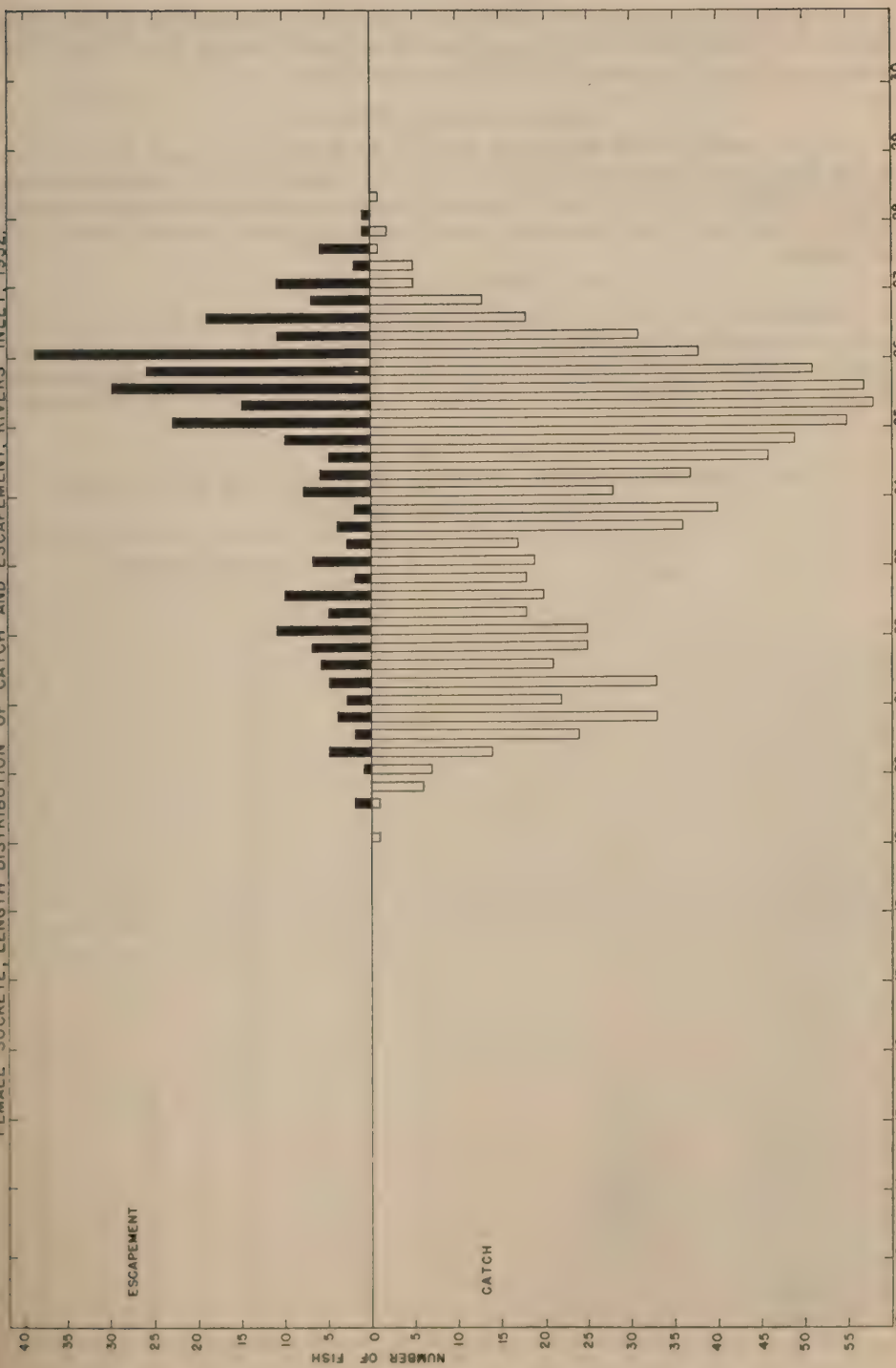


FIGURE 4.
FEMALE SOCKEYE, LENGTH DISTRIBUTION OF CATCH AND ESCAPEMENT, RIVERS INLET, 1952.

3_2 or jack was in the sample. The Smith Inlet sockeye run is marked by extreme variability in the proportion of 4_2 and 5_2 age-classes in the run in different years. Since 1945 it has varied from 92 per cent 4_2 fish to 95 per cent 5_2 fish.

(3) Lengths and Weights

The 5_2 sockeye which formed the bulk of the Smith Inlet sample in 1952 were slightly longer than in past years but were slightly below the 1951 sample in weight (Tables XXII and XXIII). The 4_2 age-class sample was within the limits of variation from previous years in both length and weight, the males being somewhat smaller than the females.

(4) Distribution of Sexes

As has been the case in all Smith Inlet samples, the 4_2 age-class has been predominantly male and the 5_2 age-class has been predominantly female (Table XXIV). The Fisheries Officer's report states that large males were predominant on the spawning-grounds. Gill-net selectivity may accordingly be responsible for the sex distribution in the catches.

Table I.—Nass River Sockeyes, Percentages of Principal Age-groups in Runs of Successive Years and Packs

Year	Percentage of Individuals			
	4_2	5_2	5_3	6_3
1912 (36,037 cases)	8	27	63	2
1913 (23,574 cases)	15	12	71	2
1914 (31,327 cases)	4	41	45	10
1915 (39,349 cases)	19	14	59	8
1916 (31,411 cases)	9	17	66	8
1917 (22,188 cases)	10	15	71	4
1918 (21,816 cases)	30	16	45	9
1919 (28,259 cases)	7	22	65	6
1920 (16,740 cases)	8	14	72	6
1921 (9,364 cases)	10	7	75	8
1922 (31,277 cases)	6	2	91	1
1923 (17,821 cases)	11	6	77	6
1924 (33,590 cases)	4	3	91	2
1925 (18,945 cases)	23	8	67	2
1926 (15,929 cases)	12	12	63	13
1927 (12,026 cases)	8	7	81	4
1928 (5,540 cases)	30	6	61	3
1929 (16,077 cases)	25	9	60	6
1930 (26,405 cases)	28	15	54	3
1931 (16,929 cases)	10	17	67	6
1932 (14,154 cases)	28	4	61	7
1933 (9,757 cases)	35	7	55	3
1934 (36,242 cases)	13	9	74	4
1935 (12,712 cases)	11	10	73	6
1936 (28,562 cases)	16	7	67	10
1937 (17,567 cases)	22	4	68	6
1938 (21,462 cases)	21	4	70	5
1939 (24,357 cases)	14	13	66	7
1940 (13,809 cases)	23	8	59	10
1941 (24,876 cases)	37	7	52	4
1942 (21,085 cases)	22	7	66	5
1943 (13,412 cases)	5	13	67	15
1944 (13,083 cases)	15	15	32	38
1945 (9,899 cases)	46	11	37	6
1946 (12,511 cases)	13	12	72	3
1947 (10,849 cases)	15	12	56	17
1948 (13,181 cases)	12	16	60	12
1949 (9,268 cases)	39	6	48	7
1950 (27,286 cases)	3	19	71	6
1951 (24,405 cases)	41	9	31	13
1952 (29,492 cases)	28	19	46	4

Table II.—Nass River Sockeyes, 1952, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals														Total
	3_1		4_1		4_2		5_2		5_3		6_3		7_4		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
19½															
19¾					1										1
20															
20¼															
20½	1					1									2
20¾	1	1													2
21	2					1									3
21¼	1			1	1	3									6
21½	1			1	2	7									11
21¾	1			1	5	4									11
22				1	4	16		1	3	3					28
22¼	1			1	2	19	1	1		6					31
22½				5	5	36	1	2	1	22					72
22¾				1	9	23		1	3	20					57
23	2			4	21	31		1	8	50					117
23¼				4	17	36			9	33					99
23½	1			1	34	34		2	19	58					149
23¾				4	31	20	2	5	17	45					124
24				5	35	22		8	30	51					151
24¼			2	1	21	10	1	7	41	45					128
24½			2	3	19	1	4	9	44	29		3			114
24¾					15	4		10	42	29		1			101
25			1		21		9	13	64	20		3			131
25¼					7		6	25	34	16		4			92
25½			1		9	2	6	16	39	16	2	1			92
25¾			1		2		9	6	22	7	1	1			49
26				1	1		4	16	29	5		1			57
26¼			2		1	1	14	13	7	2	2	1			43
26½			1		2		22	8	15		4	2			54
26¾			1				16	9	3		4				33
27							23	3	2		4	2			34
27¼				1			22	2	1		2	3			31
27½							25	1	1		4	4		1	36
27¾							7	1		1	5	1			15
28							11		1		3	3			18
28¼							6			1	2				9
28½							4				4				8
28¾							5				1				6
29							2				2				4
29¼							2				3				5
29½							2				1				3
Totals	11	1	11	35	265	271	204	160	435	459	44	30		1	1,927
Average lengths	21.8	20.8	25.4	23.4	23.9	23.1	26.8	25.3	24.8	23.9	27.6	26.3		27.5	24.5

Table III.—Nass River Sockeyes, 1952, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals														Total
	3_1		4_1		4_2		5_2		5_3		6_3		7_4		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
3					1										1
3¼															
3½								1							1
3¾															
4	3	1				8									12
4¼	1				2	8			5	2					18
4½	2			7	10	28		1		22					70
4¾	2			4	6	28	1	3		30					74
5	1			6	21	61			14	68					171
5¼				2	17	29		5	7	49					109
5½				6	33	38	3	5	21	69					175
5¾	1		1	4	24	32		5	25	40		1			133
6	1			3	34	24	3	16	43	54		2			180
6¼					32	6	1	8	43	29		1			120
6½			2	1	22	3	8	18	80	32		3			169
6¾				1	16	3	1	12	29	18	1	5			86
7			3		15	2	7	22	51	15		1			116
7¼					9		5	14	27	11	1	2			69
7½			1		13		14	13	36	8	2				87
7¾			1		3		11	8	11	3	2	2			41
8			1		4		28	19	22	9	10	2			95
8¼			1		1		19	2	3		4	2		1	33
8½			1	1		1	19	4	9		3	6			44
8¾					2		11	1			5	3			22
9							23	2	4		3				32
9¼							13	1	1		4				19
9½							10		2		1				13
9¾							7		1		2				10
10							8				2				10
10¼							2		1						3
10½							2				1				3
10¾							2				1				3
11							2								2
11¼											1				1
11½							3								3
11¾							1								1
12															
12¼															
12½											1				1
Totals	11	1	11	35	265	271	204	160	435	459	44	30		1	1,927
Average weights	4.7	4.1	7.2	5.3	6.0	5.2	8.4	6.9	6.7	5.7	8.7	7.5		8.2	6.4

Table IV.—Nass River Sockeyes, Average Lengths in Inches of Principal Age-groups, 1912 to 1952

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1912–41	24.5	23.7	26.3	25.2	26.1	25.3	27.7	26.4
1912–41 (conversion)	23.8	23.0	25.6	24.5	25.4	24.6	27.0	25.7
1942	23.9	23.2	26.1	24.9	24.9	24.3	26.9	26.0
1943	22.8	22.2	26.1	24.8	24.1	23.5	27.1	25.8
1944	23.5	22.7	25.7	24.6	24.8	23.8	26.8	25.8
1945	23.4	22.8	25.0	24.4	24.7	24.0	25.1	25.5
1946	23.4	22.4	26.3	24.9	24.9	23.9	28.1	26.0
1947	23.4	22.9	25.9	24.1	24.5	23.6	27.0	25.6
1948	23.3	22.6	26.2	25.3	25.0	24.1	27.7	26.7
1949	23.8	22.8	26.2	23.8	24.7	23.7	26.1	25.5
1950	23.6	23.1	26.0	24.7	24.5	23.7	26.7	25.6
1951	24.0	23.1	26.2	24.8	25.1	24.1	27.4	26.4
1952	23.9	23.1	26.8	25.3	24.8	23.9	27.6	26.3

Table V.—Nass River Sockeyes, Average Weights in Pounds of Principal Age-groups, 1914 to 1952

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1914–41	6.0	5.4	7.3	6.4	6.9	6.2	8.0	7.0
1942	5.8	5.1	7.1	6.3	6.2	5.6	7.5	6.7
1943	5.2	4.7	7.6	6.4	5.9	5.3	7.9	6.9
1944	5.7	5.0	7.7	6.5	6.7	5.7	8.2	7.1
1945	5.7	5.3	7.0	6.4	6.5	5.9	7.2	7.1
1946	5.6	4.9	8.1	6.7	6.5	5.4	8.9	7.0
1947	5.8	5.3	7.7	6.2	6.3	5.6	8.1	6.9
1948	5.8	5.3	8.1	7.1	7.0	6.0	9.1	7.9
1949	5.9	5.1	7.9	5.8	6.5	5.4	7.7	6.8
1950	5.9	5.2	7.9	6.6	6.4	5.5	8.2	7.1
1951	6.0	5.2	7.9	6.6	6.7	5.7	8.8	7.6
1952	6.0	5.2	8.4	6.9	6.7	5.7	8.7	7.5

Table VI.—Nass River Sockeyes, Percentages of Males and Females, 1915 to 1952

Year	4_2		5_2		5_3		6_3		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.	M.	F.		
1915–41 (average)	49	51	47	53	45	55	63	37	47	53
1942	42	58	48	52	44	56	70	30	45	55
1943	51	49	67	33	47	53	74	26	54	46
1944	53	47	45	55	39	61	60	40	50	50
1945	37	63	37	63	38	62	53	47	38	62
1946	62	38	59	41	45	55	75	25	50	50
1947	50	50	52	48	51	49	81	19	56	44
1948	45	55	54	46	52	48	66	34	53	47
1949	57	43	56	44	51	49	50	50	53	47
1950	41	59	42	58	43	57	58	42	44	56
1951	46	54	47	53	46	54	70	30	49	51
1952	49	51	56	44	49	51	59	41	50	50

Table VII.—Skeena River Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Percentage of Individuals			
	4_2	5_2	5_3	6_3
1907 (108,413 cases)	—	—	—	—
1908 (139,846 cases)	—	—	—	—
1909 (87,901 cases)	—	—	—	—
1910 (187,246 cases)	—	—	—	—
1911 (131,066 cases)	—	—	—	—
1912 (92,498 cases)	57	43	—	—
1913 (52,927 cases)	50	50	—	—
1914 (130,166 cases)	25	75	—	—
1915 (116,553 cases)	36	64	—	—
1916 (60,923 cases)	34	38	13	18
1917 (65,760 cases)	57	29	9	5
1918 (123,322 cases)	51	34	9	6
1919 (184,945 cases)	27	60	9	4
1920 (90,869 cases)	15	71	6	8
1921 (41,018 cases)	69	22	6	3
1922 (96,277 cases)	70	16	12	2
1923 (131,731 cases)	56	29	8	7
1924 (144,747 cases)	23	69	7	1
1925 (77,784 cases)	51	45	3	1
1926 (82,360 cases)	62	26	9	3
1927 (83,996 cases)	62	28	9	1
1928 (34,559 cases)	51	39	7	3
1929 (78,017 cases)	62	30	6	2
1930 (132,372 cases)	39	52	8	1
1931 (93,023 cases)	40	30	28	2
1932 (59,916 cases)	44	37	7	12
1933 (30,506 cases)	57	36	5	2
1934 (54,558 cases)	58	34	7	1
1935 (52,879 cases)	49	31	18	2
1936 (81,973 cases)	67	20	11	2
1937 (42,491 cases)	45	40	11	4
1938 (47,257 cases)	64	15	16	5
1939 (68,485 cases)	50	35	11	4
1940 (116,507 cases)	80	15	4	1
1941 (81,767 cases)	39	52	8	1
1942 (34,544 cases)	36	54	7	3
1943 (28,268 cases)	39	39	16	6
1944 (68,197 cases)	37	52	7	4
1945 (104,279 cases)	20	63	12	5
1946 (52,928 cases)	13	70	8	9
1947 (32,534 cases)	14	82	3	1
1948 (101,267 cases)	80	13	6	1
1949 (65,937 cases)	17	76	4	3
1950 (47,479 cases)	21	72	4	3
1951 (61,694 cases)	33	61	4	1
1952 (114,775 cases)	66	26	3	5

Table VIII.—Skeena River Sockeyes, 1952, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals																Total
	4_1		4_2		5_2		6_2		4_3		5_3		6_3		7_4		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
17	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17¼	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1
17½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17¾	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18¼	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18½	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18¾	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19¼	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1
19½	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	2
19¾	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
20	—	—	1	1	—	—	—	—	1	—	—	—	—	—	—	—	3
20¼	—	—	4	2	—	—	—	—	—	—	—	—	—	—	—	—	6
20½	—	—	7	2	—	—	—	—	—	—	1	—	—	—	—	—	10
20¾	—	—	3	3	—	—	—	—	—	—	1	—	—	—	—	—	7
21	—	—	16	14	—	1	—	—	—	—	2	—	—	—	—	—	33
21¼	—	—	7	28	—	—	—	—	—	—	1	2	—	—	—	—	38
21½	—	—	13	35	—	—	—	—	—	—	—	1	—	—	—	—	49
21¾	—	—	26	35	—	1	—	—	—	—	—	4	—	—	—	—	66
22	—	—	37	75	—	1	—	—	—	—	2	2	—	—	—	—	117
22¼	—	—	55	92	—	1	—	—	—	—	—	3	—	—	—	—	151
22½	—	—	57	104	—	3	—	—	—	—	2	3	—	—	—	—	169
22¾	—	—	54	56	—	4	—	—	—	—	1	2	—	1	—	—	118
23	—	—	72	97	2	7	—	—	—	—	5	4	—	2	—	—	189
23¼	—	—	72	50	5	14	—	—	—	—	6	—	1	4	—	—	152
23½	—	—	80	54	2	14	—	—	—	—	4	4	—	2	—	—	160
23¾	—	—	53	33	5	30	—	—	—	—	1	2	—	2	—	—	126
24	—	1	54	26	6	28	—	—	—	—	2	2	—	4	—	—	123
24¼	—	—	40	15	3	29	—	—	—	—	2	—	2	7	—	—	98
24½	—	—	55	11	8	46	—	—	—	—	2	2	3	3	—	—	130
24¾	—	1	43	6	12	33	—	—	—	—	1	—	2	6	—	—	104
25	—	1	22	1	17	43	—	—	—	—	1	—	2	9	—	—	96
25¼	—	—	18	1	16	46	—	—	—	—	3	—	3	7	—	—	94
25½	—	—	7	—	12	32	—	—	—	—	—	—	5	2	—	—	58
25¾	—	—	7	—	13	24	—	—	—	—	—	—	6	—	—	—	50
26	—	—	1	—	19	20	—	—	—	—	—	—	9	3	—	—	52
26¼	—	—	1	—	16	15	—	—	—	—	—	—	9	2	1	—	44
26½	—	—	1	—	17	7	—	—	—	—	—	—	10	—	—	—	35
26¾	—	—	—	—	12	5	1	—	—	—	—	—	5	—	—	—	23
27	—	—	—	—	14	—	—	—	—	—	—	—	2	—	—	—	16
27¼	—	—	—	—	5	—	—	—	—	—	—	—	4	—	—	—	9
27½	—	—	—	—	10	1	—	—	—	—	—	—	4	—	—	—	15
27¾	—	—	—	—	4	—	—	—	—	—	—	—	3	—	—	—	7
28	—	—	—	—	6	—	—	—	—	—	—	—	1	—	—	—	7
28¼	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	2
28½	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1
28¾	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1
Totals	—	3	809	742	208	405	1	—	1	—	37	31	71	54	1	—	2,363
Av. lengths	—	24.6	23.3	22.6	25.8	24.7	26.8	—	20.0	—	23.2	22.8	26.1	24.6	26.3	—	23.7

Table IX.—Skeena River Sockeyes, 1952, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals																Total
	4_1		4_2		5_2		6_2		4_3		5_3		6_3		7_4		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
2																	
2¼																	
2½			2	1													3
2¾				2													2
3			4	2							1						7
3¼			1	3													4
3½			10	9					1								20
3¾			8	9		1											18
4			28	63		3					1	2					97
4¼			34	62	1						1	2		1			101
4½			65	133		3					2	5		1			209
4¾			56	69		9					1	4					139
5			86	105	3	16					6	3	1	4			224
5¼			72	63	2	15					5	8		5			170
5½			90	77	10	46					3	3	2	8			239
5¾			49	38	3	27					3	2		4			126
6			78	47	14	52					4		5	10			210
6¼		1	41	17	9	29					3	1	3	4			108
6½			51	23	13	47					1	1	9	6			151
6¾		1	29	7	10	29					3		4	2			85
7		1	34	7	25	33	1						7	2			110
7¼			27	2	11	16					1		2	3			62
7½			17	2	18	28					1		8	2			76
7¾			8	1	10	14					1		7	1	1		43
8			11		19	14							6	1			51
8¼			4		7	7							6				24
8½			2		11	10							2				25
8¾			1		9	2							1				13
9			1		6	2							4				13
9¼					6	1							2				9
9½					7								1				8
9¾					2	1											3
10					4								1				5
10¼					4												4
10½					3												3
10¾																	
11																	
11¼					1												1
11½																	
11¾																	
Totals		3	809	742	208	405	1		1		37	31	71	54	1		2,363
Av. weights		6.7	5.6	5.0	7.5	6.4	7.1		3.6		5.6	5.0	7.4	6.0	7.8		5.8

Table X.—Skeena River Sockeyes, Average Lengths in Inches of Principal Age-groups, 1912 to 1952

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1912–41	23.7	23.1	25.8	24.9	24.2	23.4	25.8	24.8
1912–41 (conversion)	23.0	22.4	25.1	24.2	23.5	22.7	25.1	24.1
1942	22.6	22.3	25.2	24.3	24.1	23.7	26.3	24.9
1943	21.9	21.9	25.1	23.9	23.3	22.6	25.8	24.7
1944	22.4	21.7	24.8	23.9	22.5	21.7	25.0	23.7
1945	22.6	22.3	24.9	24.1	23.3	22.6	25.0	24.3
1946	22.7	22.0	25.4	24.3	23.9	23.2	25.5	24.4
1947	22.3	22.0	25.1	23.8	23.0	22.4	26.3	25.8
1948	23.0	22.3	25.3	24.1	23.0	22.1	26.0	24.5
1949	22.5	22.2	25.3	24.5	23.2	22.3	24.8	23.9
1950	22.8	22.3	25.7	24.4	23.9	23.4	25.5	24.3
1951	22.7	22.6	25.9	24.8	23.6	22.9	26.0	24.6
1952	23.3	22.6	25.8	24.7	23.2	22.8	26.1	24.6

Table XI.—Skeena River Sockeyes, Average Weights in Pounds of Principal Age-groups, 1914 to 1952

Year	4_2		5_2		5_3		6_3	
	M.	F.	M.	F.	M.	F.	M.	F.
1914–41	5.4	5.0	6.8	6.1	5.7	5.1	6.8	6.0
1942	4.9	4.7	6.7	6.0	5.8	5.4	7.2	6.6
1943	4.7	4.6	6.8	5.9	5.5	4.9	7.3	6.1
1944	5.1	4.6	7.0	6.1	5.3	4.6	7.1	5.8
1945	5.2	4.9	6.7	6.1	5.6	5.0	6.7	6.2
1946	4.7	4.2	6.9	5.8	5.8	5.1	7.0	6.1
1947	4.9	4.7	6.9	5.9	5.3	5.0	7.7	6.8
1948	5.5	4.9	7.3	6.1	5.4	4.7	7.7	6.4
1949	5.0	4.7	7.1	6.3	5.3	4.8	6.6	5.7
1950	4.8	4.3	7.2	5.9	5.8	5.1	6.8	5.6
1951	5.1	5.0	7.6	6.5	5.6	5.0	7.6	6.4
1952	5.6	5.0	7.5	6.4	5.6	5.0	7.4	6.0

Table XII.—Skeena River Sockeyes, Percentages of Males and Females, 1915 to 1952

Year	4_2		5_2		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.		
1915–41 (average)	48	52	43	57	46	54
1942	42	58	25	75	33	67
1943	50	50	31	69	43	57
1944	54	46	34	66	43	57
1945	41	59	35	65	38	62
1946	50	50	32	68	38	62
1947	50	50	29	71	33	67
1948	50	50	29	71	47	53
1949	54	46	30	70	36	64
1950	56	44	40	60	44	56
1951	41	59	37	63	39	61
1952	52	48	34	66	48	52

Table XIII.—Rivers Inlet Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Percentage of Individuals			
	4_2	5_2	5_3	6_3
1907 (87,874 cases)	—	—	—	—
1908 (64,652 cases)	—	—	—	—
1909 (89,027 cases)	—	—	—	—
1910 (126,921 cases)	—	—	—	—
1911 (88,763 cases)	—	—	—	—
1912 (112,884 cases)	21	79	—	—
1913 (61,745 cases)	80	20	—	—
1914 (89,890 cases)	35	65	—	—
1915 (130,350 cases)	13	87	—	—
1916 (44,936 cases)	26	74	—	—
1917 (61,195 cases)	39	61	—	—
1918 (53,401 cases)	57	43	—	—
1919 (56,258 cases)	46	54	—	—
1920 (121,254 cases)	5	95	—	—
1921 (46,300 cases)	49	51	—	—
1922 (60,700 cases)	81	18	1	—
1923 (107,174 cases)	74	24	2	—
1924 (94,891 cases)	43	54	2	1
1925 (159,554 cases)	23	77	—	—
1926 (65,581 cases)	59	38	2	1
1927 (64,461 cases)	81	16	3	—
1928 (60,044 cases)	55	40	4	1
1929 (70,260 cases)	77	18	3	2
1930 (119,170 cases)	49	48	2	1
1931 (76,428 cases)	53	44	2	1
1932 (69,732 cases)	67	27	5	1
1933 (83,507 cases)	44	55	1	—
1934 (76,923 cases)	77	20	2	1
1935 (135,038 cases)	57	41	1	1
1936 (46,351 cases)	53	46	1	—
1937 (84,832 cases)	60	37	3	—
1938 (87,942 cases)	27	70	1	2
1939 (54,143 cases)	67	32	1	—
1940 (63,469 cases)	69	28	3	—
1941 (93,378 cases)	59	40	1	—
1942 (79,199 cases)	8	91	—	1
1943 (47,602 cases)	8	91	—	1
1944 (36,852 cases)	76	23	1	—
1945 (89,735 cases)	57	41	2	—
1946 (73,320 cases)	37	63	—	—
1947 (140,087 cases)	3	97	—	—
1948 (37,665 cases)	55	44	1	—
1949 (39,495 cases)	84	14	1	—
1950 (142,710 cases)	13	87	(1)	—
1951 (102,565 cases)	38	60	1	1
1952 (84,298 cases)	41	58	1	(1)

[1] Age-class represented but less than 0.5 per cent.

Table XIV.—Rivers Inlet Sockeyes, 1952, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals												Total
	3_2		4_2		5_2		6_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
16	1												1
16¼													
16½													
16¾													
17													
17¼													
17½													
17¾			1										1
18													
18¼													
18½			1										1
18¾			1										1
19			2	1									3
19¼			6										6
19½			6	1									7
19¾			13	6									19
20			17	7	1								25
20¼			29	14									43
20½			32	24									56
20¾			36	32					2	1			71
21			40	22									62
21¼			27	32		1							60
21½			20	20						1			41
21¾			14	25					1				40
22			19	22		2				1			44
22¼			15	12	4	6			1				38
22½			13	17	2	2				1			35
22¾			6	10	1	8							25
23			10	7	5	12							34
23¼			10	4	3	11				2			30
23½			13	8	15	26				1		1	64
23¾			11	3	6	36				1			57
24			5	2	6	26			1				40
24¼			13		14	37							64
24½			2		10	46							58
24¾			5		11	49							65
25			5		7	53						2	67
25¼			3		9	58			1				71
25½					8	57							65
25¾					15	51							66
26					22	38							60
26¼					30	31							61
26½					19	18							37
26¾					21	13							34
27					24	5							29
27¼					26	5							31
27½					13			1					14
27¾					13	2							15
28					11								11
28¼					5	1							6
28½					4								4
28¾					2								2
29					2								2
29¼					2								2
Totals	1		375	269	311	594		1	6	8		3	1,568
Average lengths	16.0		21.5	21.5	26.0	25.0		27.5	22.5	22.6		24.5	23.7

Table XV.—Rivers Inlet Sockeyes, 1952, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals												Total
	3_2		4_2		5_2		6_2		5_3		6_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
2	1												1
2¼													
2½													
2¾													
3			2	1									3
3¼													
3½			11	7									18
3¾			27	10									37
4			49	34		1			1	1			86
4¼			41	43		1			1				86
4½			63	54	3	1				2			123
4¾			34	26		3				1			64
5			29	38	3	8			1	1			80
5¼			15	18	1	9							43
5½			23	10	5	19			1	1			59
5¾			12	6	3	9				2			32
6			12	14	8	28			1				63
6¼			9	6	8	22						1	46
6½			19	1	10	50							80
6¾			5	1	9	27							42
7			6		17	51			1			1	76
7¼			4		8	48							60
7½			10		10	55						1	76
7¾					6	44							50
8			3		13	54							70
8¼			1		11	30							42
8½					22	46							68
8¾					19	23							42
9					21	31							52
9¼					16	12							28
9½					24	11							35
9¾					10	3							13
10					23	6							29
10¼					10								10
10½					10	1		1					12
10¾					7	1							8
11					12								12
11¼					5								5
11½					10								10
11¾					2								2
12					3								3
12¼					1								1
12½					1								1
Totals	1		375	269	311	594		1	6	8		3	1,568
Average weights	2.0		4.9	4.7	8.8	7.4		10.6	5.3	5.0		7.0	6.6

Table XVI.—Rivers Inlet Sockeyes, Average Lengths in Inches of the 4_2 and 5_2 Groups, 1912 to 1952

Year	4_2		5_2	
	M.	F.	M.	F.
1912–41	22.4	22.4	25.4	24.7
1912–41 (conversion)	21.6	21.6	24.6	23.9
1942	21.9	21.3	25.0	23.8
1943	20.5	21.1	24.3	23.7
1944	21.1	21.0	23.5	23.3
1945	20.9	21.2	24.2	23.9
1946	20.6	21.1	25.1	24.1
1947	20.6	20.7	24.0	23.5
1948	21.4	21.3	25.2	24.2
1949	20.9	21.4	23.8	22.8
1950	21.1	20.8	25.2	24.2
1951	21.9	21.9	25.8	24.8
1952	21.5	21.5	26.0	25.0

Table XVII.—Rivers Inlet Sockeyes, Average Weights in Pounds of the 4_2 and 5_2 Groups, 1914 to 1952

Year	4_2		5_2	
	M.	F.	M.	F.
1914–41	4.9	4.8	7.0	6.5
1942	5.1	4.6	7.2	6.4
1943	4.1	4.4	6.8	6.3
1944	4.6	4.4	6.2	6.0
1945	4.3	4.4	6.6	6.4
1946	3.9	3.9	7.2	6.2
1947	4.1	3.9	6.4	5.9
1948	4.7	4.6	7.9	7.0
1949	4.4	4.3	5.9	5.9
1950	4.2	3.9	7.5	6.4
1951	5.2	5.0	8.6	7.4
1952	4.9	4.7	8.7	7.4

Table XVIII.—Rivers Inlet Sockeyes, Percentages of Males and Females, 1915 to 1952

Year	4_1		4_2		5_2		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.		
1915–41 (average)			63	37	34	66	50	50
1942			61	39	35	65	38	62
1943			62	38	34	66	36	64
1944			67	33	33	67	59	41
1945			70	30	39	61	57	43
1946			79	21	37	63	53	47
1947			72	28	35	65	36	64
1948			50	50	38	62	45	55
1949	36	64	70	30	22	78	63	37
1950	50	50	75	25	36	64	41	59
1951			66	34	30	70	44	56
1952			58	42	34	66	44	56

Table XIX.—Smith Inlet Sockeyes, Percentages of Age-groups in Runs of Successive Years and Packs

Year	Percentage of Individuals				
	4_1	4_2	5_2	6_2	5_3
1925 (33,764 cases)	—	—	—	—	—
1926 (17,921 cases)	—	—	—	—	—
1927 (22,682 cases)	—	—	—	—	—
1928 (33,442 cases)	—	—	—	—	—
1929 (9,683 cases)	—	—	—	—	—
1930 (32,057 cases)	—	—	—	—	—
1931 (12,867 cases)	—	—	—	—	—
1932 (25,488 cases)	—	—	—	—	—
1933 (37,369 cases)	—	—	—	—	—
1934 (14,607 cases)	—	—	—	—	—
1935 (31,648 cases)	—	—	—	—	—
1936 (12,788 cases)	—	—	—	—	—
1937 (25,258 cases)	—	—	—	—	—
1938 (33,894 cases)	—	—	—	—	—
1939 (17,833 cases)	—	—	—	—	—
1940 (25,947 cases)	—	—	—	—	—
1941 (21,495 cases)	—	—	—	—	—
1942 (15,939 cases)	—	—	—	—	—
1943 (15,010 cases)	—	—	—	—	—
1944 (3,165 cases)	—	—	—	—	—
1945 (15,014 cases)	—	50	50	—	—
1946 (14,318 cases)	—	11	89	—	—
1947 (36,800 cases)	—	5	95	—	—
1948 (10,456 cases)	—	7	90	3	—
1949 (13,189 cases)	2	92	5	—	(1)
1950 (42,435 cases)	—	17	83	—	(1)
1951 (49,473 cases)	—	22	77	(1)	(1)
1952 (34,834 cases)	—	8	91	(1)	1

[1] This age-class was represented by less than 0.5 per cent of the number of fish in the sample.

Table XX.—Smith Inlet Sockeyes, 1952, Grouped by Age, Sex, Length, and by Their Early History

Length in Inches	Number of Individuals										Total
	3_2		4_2		5_2		6_2		5_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
16											
16¼	1										1
16½											
16¾											
17											
17¼											
17½											
17¾											
18											
18¼											
18½											
18¾											
19											
19¼			1								1
19½											
19¾			1								1
20			1		1						2
20¼			1	1					1		3
20½			3								3
20¾			4	1							5
21				1							1
21¼			6	1							7
21½			1	2					1		4
21¾			1	1							2
22			5	3							8
22¼			2	4						2	8
22½			3	3		1					7
22¾			1	19		5			1		8
23			2	3	1	5					11
23¼			3	4		8					15
23½				1	2	13					16
23¾			1	2		16					19
24					6	29					35
24¼				1	10	47					58
24½					17	55					72
24¾					19	39		1	1	1	61
25			1		27	72			1		101
25¼					25	61					86
25½					28	47		1			76
25¾			1		33	34					68
26					31	44					75
26¼					37	10					47
26½					29	8					37
26¾					16	3					19
27					9	4					13
27¼					9						9
27½					3						3
27¾					2						2
28					2						2
28¼					1						1
Totals	1		38	29	308	501		2	5	3	887
Average lengths	16.3		21.8	22.4	25.7	24.9		25.1	22.9	23.1	25.0

Table XXI.—Smith Inlet Sockeyes, 1952, Grouped by Age, Sex, Weight, and by Their Early History

Weight in Pounds	Number of Individuals										Total
	3_2		4_2		5_2		6_2		5_3		
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.	
2	1		—	—	—	—	—	—	—	—	1
2¼			—					—	—		
2½								—	—		
2¾									—		
3			—	—	—	—	—	—	—	—	—
3¼		—	—	—	—	—	—	—	—	—	—
3½			2	—	—	—	—	—	—	—	2
3¾			1	—		—	—	—	—	—	1
4		—	7	1	1	—	—	—	1	—	10
4¼			1	2	—	—	—	—	—	—	3
4½		—	7	5	1	3	—	—	—	1	17
4¾		—	4	1	—	—	—	—	1	—	6
5		—	7	7	—	10	—	—	1	1	26
5¼			1	1	—	2	—	—	—	—	4
5½			2	6	2	19	—	—	—	—	29
5¾			1	2	—	1	—	—	—	—	4
6			2	3	10	55	—	1	—	—	71
6¼		—	1	—		4	—	—	—	—	5
6½			—	1	20	69	—	—	—	—	90
6¾			—	—	2	6	—	—	1	1	10
7		—	—	—	44	102	—	—	—	—	146
7¼			1	—	3	19	—	—	—	—	23
7½			1	—	35	75	—	—	—	—	111
7¾	—	—	—	—	6	10	—	—	—	—	16
8			—	—	56	67	—	—	—	—	123
8¼		—	—	—	7	14	—	—	1	—	22
8½		—	—	—	48	20	—	1	—	—	69
8¾		—	—	—	3	3	—	—	—	—	6
9				—	34	15	—	—	—	—	49
9¼				—	3	3	—	—	—	—	6
9½			—	—	17	3	—	—	—	—	20
9¾			—	—	5	1	—	—	—	—	6
10			—	—	4	—	—	—	—	—	4
10¼				—	2	—	—	—	—	—	2
10½			—	—	3	—	—	—	—	—	3
10¾											
11			—	—	1	—	—	—	—	—	1
11¼			—	—	1	—	—	—	—	—	1
Totals	1		38	29	308	501	—	2	5	3	887
Average weight	2.0		4.8	5.2	8.0	7.1	—	7.3	5.7	5.4	7.2

Table XXII.—Smith Inlet Sockeyes, Average Lengths in Inches of Age-groups, 1945 to 1952

Year	4_1		4_2		5_2		6_2		5_3	
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.
1945	—	—	22.2	22.0	25.1	24.4	—	—	—	—
1946	—	—	21.3	22.7	24.7	24.0	—	—	—	—
1947	—	—	23.2	23.4	25.2	24.3	—	—	—	—
1948	—	—	21.9	21.7	25.0	24.3	26.7	25.0	—	—
1949	25.4	23.5	21.4	21.7	24.6	24.3	—	25.5	—	—
1950	—	—	21.6	21.7	24.8	24.0	—	—	20.5	—
1951	—	—	22.8	22.0	25.6	24.8	—	25.1	23.4	
1952	—	—	21.8	22.4	25.7	24.9	—	25.1	22.9	23.1

Table XXIII.—Smith Inlet Sockeyes, Average Weights in Pounds of Age-groups, 1945 to 1952

Year	4_1		4_2		5_2		6_2		5_3	
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.
1945			4.9	4.7	7.1	6.5	—	—	—	—
1946	—	—	4.6	5.8	7.3	6.6	—	—	—	—
1947		—	5.7	5.5	6.9	6.0	—	—	—	—
1948			5.1	5.4	7.6	6.9	10.3	7.5	—	—
1949	7.9	6.1	5.0	5.1	7.2	6.7	—	7.3	—	—
1950	—	—	4.9	5.0	7.4	6.6	—	—	4.0	—
1951	—	—	6.0	5.2	8.2	7.3	—	7.2	6.4	—
1952	—	—	4.8	5.2	8.0	7.1	—	7.3	5.7	5.4

Table XXIV.—Smith Inlet Sockeyes, Percentages of Males and Females, 1945 to 1952

Year	4_1		4_2		5_2		6_2		5_3		Per Cent Total Males	Per Cent Total Females
	M.	F.	M.	F.	M.	F.	M.	F.	M.	F.		
1945	—	—	73	27	49	51	—	—	—	—	61	39
1946	—	—	76	24	37	63	—	—	—	—	41	59
1947	—	—	38	62	47	53	—	—	—	—	46	54
1948	—	—	79	21	42	58	11	89	—	—	43	57
1949	36	64	80	20	40	60	—	100	—	—	77	23
1950	—	—	86	14	42	58	—	—	100	—	49	51
1951	—	—	72	28	41	59	—	100	100	—	48	52
1952	—	—	57	43	38	62	—	100	63	37	40	60

Table XXV.—Spawning Escapement Length Distribution,[1] Rivers Inlet

Length in Inches	Males	Females	Total	Length in Inches	Males	Females	Total
12¼	1	—	1	21¾	5	7	12
12½	—	—	—	22	3	11	14
12¾	3	—	3	22¼	2	5	7
13	2	—	2	22½	2	10	12
13¼	4	—	4	22¾	1	2	3
13½	11	—	11	23	2	7	9
13¾	11	—	11	23¼	—	3	3
14	16	—	16	23½	—	4	4
14¼	17	—	17	23¾	3	2	5
14½	13	—	13	24	4	8	12
14¾	11	—	11	24¼	5	6	11
15	4	—	4	24½	1	5	6
15¼	6	—	6	24¾	2	10	12
15½	5	—	5	25	2	23	25
15¾	1	—	1	25¼	5	15	20
16	—	—	—	25½	4	30	34
16¼	1	—	1	25¾	1	26	27
16½	2	—	2	26	3	39	42
16¾	—	—	—	26¼	4	11	15
17	—	—	—	26½	3	19	22
17¼	—	—	—	26¾	9	7	16
17½	3	—	3	27	11	11	22
17¾	2	—	2	27¼	17	2	19
18	3	—	3	27½	11	6	17
18¼	—	—	—	27¾	15	1	16
18½	5	—	5	28	25	1	26
18¾	2	—	2	28¼	14	—	14
19	10	—	10	28½	32	—	32
19¼	16	—	16	28¾	18	—	18
19½	16	2	18	29	21	—	21
19¾	18	—	18	29¼	18	—	18
20	26	1	27	29½	11	—	11
20¼	15	5	20	29¾	5	—	5
20½	18	2	20	30	3	—	3
20¾	7	4	11	30¼	3	—	3
21	14	3	17	30½	3	—	3
21¼	5	5	10				
21½	3	6	9	Totals	539	299	838

[1] This length is not strictly comparable to that of fish taken in the commercial fishery due to the changes which occur with sexual maturity.

VICTORIA, B.C.
Printed by DON MCDIARMID, Printer to the Queen's Most Excellent Majesty.
1953

1,150-953-5363

363

BRITISH COLUMBIA DEPARTMENT OF FISHERIES, 1953

Results of Investigation of the Herring Populations on the West Coast and Lower East Coast of Vancouver Island in 1952-53

With an Analysis of Fluctuations in Population Abundance since 1946-47

BY

J. C. STEVENSON, M.A., AND D. N. OUTRAM, B.A.,
PACIFIC BIOLOGICAL STATION, NANAIMO, B.C.

[REPRINTED WITHOUT CHANGE OF PAGING FROM THE REPORT OF THE BRITISH COLUMBIA DEPARTMENT OF FISHERIES, 1952.]

RESULTS OF INVESTIGATION OF THE HERRING POPULATIONS ON THE WEST COAST AND LOWER EAST COAST OF VANCOUVER ISLAND IN 1952–53, WITH AN ANALYSIS OF FLUCTUATIONS IN POPULATION ABUNDANCE SINCE 1946–47.

By J. C. Stevenson, M.A., and D. N. Outram, B.A.,
Pacific Biological Station, Nanaimo, B.C.

CONTENTS

	Page
Introduction	57
The 1952–53 Fishery	58
Tagging and Tag-recovery	60
Sampling of Winter Runs and Spawning Stocks	61
Age Composition	62
West Coast Population	62
Lower East Coast Population	63
Sex Ratio and Stage of Development	65
West Coast Population	65
Lower East Coast Population	65
Average Length and Weight	67
Extent and Intensity of Spawning	68
West Coast Population	68
Lower East Coast Population	69
Population Abundance in 1952–53	70
Catch, Spawn, and Abundance	71
Summary	77
Acknowledgments	78
References	79
Tables	80

INTRODUCTION

From 1946–47 to 1951–52 the herring population of the west coast of Vancouver Island was fished without catch quota restrictions, while a fixed quota of 40,000 tons was maintained on the herring population of the lower east coast of Vancouver Island. A fishing-closure date of February 5th was applied to each population. The contrasting catch regulations formed the basis for long-term scientific investigation of the effectiveness of catch quotas in stabilizing herring populations. The investigation is complicated by the existence of natural fluctuations in year-class strength. Effort is concentrated on comparing the extent of these fluctuations and possible changes in abundance caused by virtually unrestricted fishing.

The results of the first six years of investigation have been outlined in an annual series of reports.* Generally high abundance characterized both populations in the first five years. In the sixth year (1951–52), population abundance continued high on the lower east coast, but decreased sharply on the west coast. The reduced west coast abundance was not considered to be caused by the lack of quota restrictions, but rather

* Previous publications in this series are Tester and Stevenson, 1947, 1948; Stevenson, 1950; Stevenson and Lanigan, 1950; Stevenson, Hourston, and Lanigan, 1951; and Stevenson, Hourston, Jackson, and Outram, 1952.

to poor year-class survival and lowered recruitment. Continuation of the investigation appeared necessary to determine whether unrestricted fishing on the west coast would seriously reduce the spawning stock when generally low abundance prevailed.

The opportunity to study the effect of non-quota fishing on the lowered west coast abundance was lost, at least for the present, when the regular reduction fishery did not develop in 1952–53 because of inability of fishing companies and fishermen to agree on prices to be paid for the catch. The curtailed catch also hampered the collection of various data* useful in studying population abundance. Sampling of the west coast winter runs was accomplished through borrowing vessels from the industry; this method of sampling was used to a smaller extent on the lower east coast, since a fishery for salting developed there. Tag-recovery, which depends upon herring being brought into reduction plants, was not possible in the 1952–53 season.

The present, and seventh, report of the series deals with results of investigation of the west coast and lower east coast populations in 1952–53. The data pertaining to changes in population abundance from 1951–52 to 1952–53 are analysed, and a method is developed whereby abundance during each of the seven years of the study is related to catch and spawn deposition.

Research on Pacific herring (*Clupea pallasi*) is carried out at the Pacific Biological Station, Nanaimo, B.C., by the Fisheries Research Board of Canada. In addition to studies on the adult stocks of the two populations discussed in the report, investigation is undertaken on all other major herring populations of British Columbia. Studies are also carried out on survival during early life-history stages; the chief study of the latter investigations concerns the possible relationship between abundance of juvenile (1-year) herring and year-class recruitment.

A map of the Southern British Columbia coast is given in Fig. 1, on which are indicated the statistical areas into which the west coast and lower east coast sub-districts are divided, as well as some of the place-names mentioned in the text and supplementary tables.

THE 1952–53 FISHERY

Negotiations between fishing companies and the fishermen's union to determine the price to be paid for the 1952–53 catch began on October 21st, and continued until the end of the year, with no settlement being reached. As a result, only a small quantity of herring was caught for reduction purposes in 1952–53, and most of that was taken in a summer seine-fishery on the lower east coast of Vancouver Island. By special arrangements a small fishery developed on the lower east coast during the winter to procure herring for salting and for bait. Only 11,800 tons of herring were taken in British Columbia waters, as compared to 198,000 tons in the previous year. The lower east coast catch totalled 8,085 tons (68 per cent of the British Columbia catch), of which 6,130 tons were processed as salted herring. The west coast fishery amounted to only 20 tons, all of which was caught in Area 24 and used for bait. In the 1951–52 season, 41,000 and 30,000 tons were taken in the lower east coast and west coast sub-districts respectively. Table I shows the amounts of fish caught by different fishing-gear and processed by various methods during the 1952–53 season in each population.

Six seiners and four trawlers took part in the lower east coast fishery. Seining accounted for about 95 per cent of the catch, and the two seiners that fished for the salteries from October 15th to the closure date of February 5th were responsible for over three-quarters of the lower east coast catch. Most of the seining (98 per cent) was carried out in Nanoose Bay and near Dodd Narrows in Area 17A. Fish were sufficiently abundant in these localities to obviate the need of intensive searching elsewhere.

* A detailed analysis of the implications of the absence of a regular herring-fishery in 1952–53 on herring research is given by the senior author in the Pacific Biological Station Circular No. 27. Phases of research in which collection of data was not possible or made more difficult are discussed, as are phases of research in which the reduced fishing will provide new data.

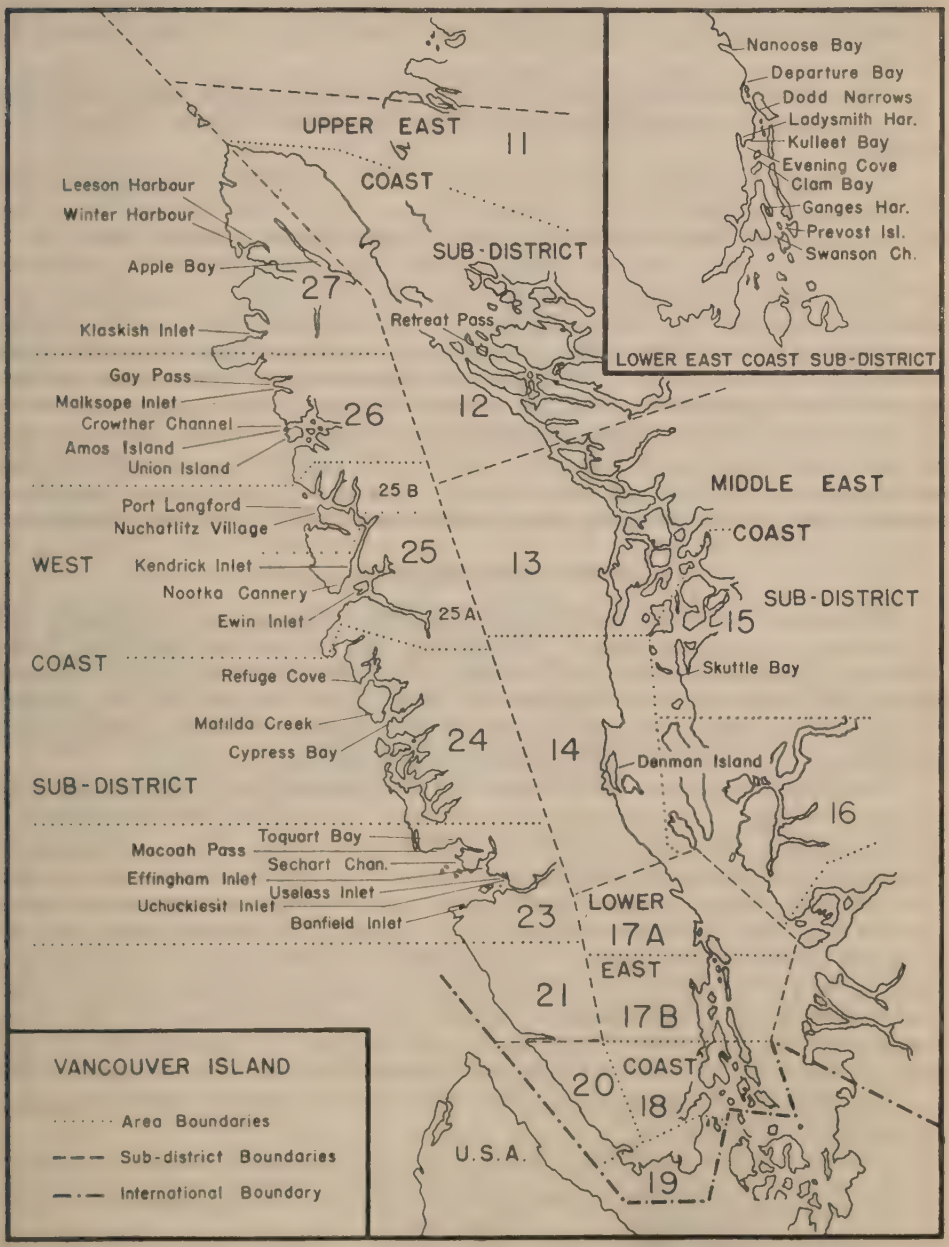


Fig. 1. Map showing the statistical areas into which the sub-districts of the southern British Columbia coast are divided, and including some of the place-names mentioned in the text and supplementary tables.

Fishing by seine was limited much more by the capacities of the two salteries (located on Reid Island in Area 17B and on North Pender Island in Area 18) than by availability of fish.

The summer seine-catch, mostly for reduction, was taken from June 22nd to July 12th. It amounted to over 400 tons, and most of the fish were caught in Nanoose Bay in Area 17A.

Trawling for herring was conducted mostly with an ordinary otter-trawl lined with herring-web, and a catch of 340 tons was obtained. Most of the trawl-catch was taken in the vicinity of Trincomali Channel (Area 17B) and Swanson Channel (Area 18).

Only one of the six seiners submitted catch records from which fishing effort and availability could be calculated. About 30 per cent of the lower east coast catch was taken by this seiner. Average availability for this vessel amounted to 107.3 tons per seine per day, a value which is high in comparison to average figures in previous years. However, the fact that this value is based on only one seiner, as well as the fact that only six seiners operated in 1952–53 as against about forty in other years, throws doubt on whether this availability value can be compared with those of other years in assessing the relative abundance in inshore waters. One trawler submitted records which showed an average catch of 4 tons per hour's fishing. Absence or near-absence of trawling in previous years prevents using this value in interpreting present population abundance.

TAGGING AND TAG-RECOVERY

Opportunity to recover herring-tags in the 1952–53 season was very limited, and, as a result, no tags were returned. Herring-tags can be recovered only from herring processed at reduction plants, and less than 1,500 tons of the total British Columbia herring-catch were reduced to meal and oil. Most of this amount (over 80 per cent) was processed at a reduction plant in which recovery equipment had not been previously installed and where installation of equipment was not feasible in 1952–53.

The curtailed fishery in 1952–53 provides an opportunity of determining the extent of natural mortality in the major herring populations, by comparing the concentration of the 1952 and the 1953 tags in the 1953–54 catches (Stevenson, 1953). A large coast-wise tagging programme was therefore undertaken in the spring of 1953, with consider-able care being taken to carry out taggings in the same localities and at the same times as those of the spring of 1952. In addition, fish were tagged in localities not before included in tagging surveys for the purpose of gaining additional knowledge on the geographical limits of the various stocks. As a result, the 1953 tagging programme was the largest ever carried out on British Columbia herring. Forty individual taggings* were made, twenty-seven of which were comparable in place and time to taggings of the previous year. A total of 81,390 fish was tagged, about one-third greater than was tagged in 1952.

The numbers of herring tagged in the various areas in 1952 and 1953 are given in the following tabulation:—

Year	Sub-district and Area of Tagging														
	Queen Charlotte Islands	Northern	Central		Upper East Coast	Middle East Coast		Lower East Coast			West Coast				
	2B(E)	4	6	7	12	14	15	17A	17B	18	23	24	25	26	27
1952	4,114	8,089	.....	8,837	.....	3,013	.....	5,034	5,540	.....	10,058	5,071	8,058	3,073	.....
1953	4,111	6,244	2,084	13,526	1,342	3,982	2,026	4,051	7,178	1,987	15,688	4,764	7,767	4,612	2,028

*A list of all taggings made in 1953, including information on the date and place of each tagging, will be supplied on request (Supplementary Table I).

Three vessels, borrowed from the fishing companies, were used in the tagging surveys. Two vessels commenced operation on the west coast of Vancouver Island in the last week of February, and moved to the central sub-district about the middle of March. One of these vessels later went to the northern sub-district, while the other proceeded to the Queen Charlotte Islands. The third vessel began operations in late February on the lower east coast of Vancouver Island, moving north to the middle and upper east coasts of Vancouver Island and to more southerly parts of the central sub-district. All vessels finished tagging by early April.

SAMPLING OF WINTER RUNS AND SPAWNING STOCKS

Sampling involves the collection of random samples of herring from the winter and spawning runs, and the determination of age, growth, sex ratio, and sexual development of the fish comprising the samples. A brief outline of the details of the sampling procedure was given in the first report of this series (Tester and Stevenson, 1947).

The collection of herring samples from the west coast of Vancouver Island during the winter of 1952–53 was accomplished through the operation of seine-boats borrowed from the fishing industry. The taking of samples from the commercial catches was not possible on the west coast because of the almost complete absence of a commercial herring-fishery in the 1952–53 season. Although fishing for reduction purposes likewise did not develop along the lower east coast of Vancouver Island, samples of the winter runs were readily provided by the salt-herring fishery which took place in that sub-district. As in previous years, the regular tagging programme in the spring of 1953 permitted sampling of the spawning runs of both populations.

In spite of the sampling difficulties arising from the lack of fishing for reduction purposes, more samples* were taken than in the previous year (184 as compared to 146). Increased sampling of the spawning runs was an important factor in obtaining a greater total number of samples. The distribution of the sampling in the lower east coast and west coast population is indicated in the following tabulation (with comparable data for 1951–52 in parentheses):—

	Number of Samples			
	Winter Runs		Spawning Runs	
Lower east coast—				
Area 17A	72	(37)	3	(2)
Area 17B	20	(0)	5	(2)
Area 18	8	(42)	1	(0)
Totals	100	(79)	9	(4)
West coast—				
Area 23	25	(16)	14	(5)
Area 24	3	(1)	4	(2)
Area 25A	3	(0)	4	(0)
Area 25B	9	(37)	4	(1)
Area 26	3	(0)	4	(1)
Area 27	0	(0)	2	(0)
Totals	43	(54)	32	(9)
Grand Total	143	(133)	41	(13)

* Lists of all winter and spawning samples taken on the west coast and the lower east coast of Vancouver Island in 1952–53, including places and dates of sampling, numbers of fish of each age and of each sex, and data on maturity, will be supplied on request (Supplementary Tables II and III respectively).

Age Composition

West Coast Population

The average percentage age composition for the west coast population as derived from samples taken during the winter months is given below for recent seasons. The data were weighted to numbers of fish caught in each statistical area for all seasons except that of 1952–53; for the last season, weighting was according to the number of samples taken in each area.

Season	In Year of Age								
	I	II	III	IV	V	VI	VII	VIII	IX–XI
1948–49	+	7.4	45.2	32.9	9.6	3.4	1.0	0.3	0.1
1949–50	+	4.4	68.8	20.5	5.3	0.8	0.2	0.1	0.0
1950–51	+	9.8	35.3	44.5	8.0	1.9	0.5	+	+
1951–52	+	2.6	36.2	23.9	31.6	4.3	1.2	0.2	+
1952–53[1]	0.1	7.3	61.7	28.5	1.8	0.5	0.1	0.0	0.0

[1] Samples from Area 25A, which were mainly composed of unrecruited II-year fish, were not considered in calculating the average age composition in 1952–53.

In 1952–53 the 1947 year-class failed to comprise a large proportion of the west coast stocks. Its remarkably large contribution to the stocks of the three previous years has marked it as the most abundant year-class of recent years. As III-year fish in 1949–50 it constituted over two-thirds of the catch; as IV-year fish in 1950–51 it formed almost half the catch; and as V-year fish in 1951–52 it made up nearly one-third of the catch. The poor representation of this year-class as VI-year fish in 1952–53 was predicted (Stevenson, Hourston, Jackson, and Outram, 1952), the basis of the prediction being that recruitment to the adult stocks after the fifth year is always relatively small.

The 1948 year-class in 1952–53 provided the smallest percentage of V-year fish ever noted in west coast runs. This fact, together with the poor contribution of the year-class as IV-year fish in the 1951–52 season, points to the relative weakness of the year-class.

The 1949 year-class (IV-year fish in 1952–53), although showing signs of being weak in 1951–52 catches, appears to be of about average abundance on the basis of the current data.

The 1950 year-class (III-year fish) entered west coast catches strongly in 1952–53. The proportion of III-year fish in the runs was greater than in any recent year, except in 1949–50, when the unusually abundant 1947 year-class entered the runs in force. Although the relative abundance of the 1950 year-class is high* in comparison with other year-classes in the 1952–53 runs, and although its relative abundance is also high compared to other year-classes at the same age in previous seasons, information on the absolute population abundance (in terms of numbers of fish) is, of course, essential to determine whether the year-class is large. The lack of fishing in the current season has prohibited the obtaining of the usual catch data, from which an indication of population size could be obtained. However, on the reasonable assumption that west coast abundance was at least as great as in the previous year, it appears that the 1950 year-class is of above average strength.

This indication of the strength of the 1950 year-class differs from that obtained from age-composition data in 1951–52 (Stevenson, Hourston, Jackson, and Outram, 1952). In that season this year-class comprised an unusually small proportion of the fishing stocks (2.6 per cent), a generally reliable indication of low year-class abundance.

* It is possible that the relative abundance of the 1950 year-class in the 1952–53 runs was not determined as accurately by sampling with a single seine-boat, fishing non-commercially, as it would have been if sampling had been carried out on catches from an extensive fishery as in previous years.

A statistically significant correlation has been found (Stevenson, unpublished) between the abundance of II-year fish and the total abundance of the year-class (in all seasons of recruitment) for each west coast year-class from 1939 to 1949 (r=0.79; P=0.01). (The method of assessing year-class strength is that used by Tester, 1948.)

The relatively large proportion of II's in the 1952–53 winter runs (1951 year-class) appears to indicate that the 1951 year-class will be above average in abundance.

The age composition of the winter runs of herring in the more southerly areas of the west coast (Areas 23 and 24) differed considerably from that of the runs in the more northerly areas (Areas 25B and 26): the 1949 and 1951 year-classes were relatively more prominent in the south than in the north, while the 1950 year-class was more abundant in the north (forming three-quarters of the runs) than in the south (Table II and Fig. 2). The greater strength of the 1949 year-class in the south was indicated in the 1951–52 sampling data (Stevenson, Hourston, Jackson, and Outram, 1952).

The three samples taken in Area 25A (from a single large school) were almost wholly comprised of II-year fish (1951 year-class). The run represented by these samples was presumably composed of herring not yet recruited to the adult stocks.

The age-composition data from the spawning runs (Table II) showed, as did the data from the winter runs, that the 1951 year-class (II-year fish) was more abundant in the southern areas than in the northern areas. The spawning samples also suggested that runs of older fish were not sampled during the winter. The once abundant 1947 year-class comprised a percentage of the winter runs that is usual for VI-year fish, but the proportion of the spawning runs that belong to this year-class (particularly in Area 25) was much higher than has ever been found for VI-year fish. It is presumed that these runs of older fish were missed in the winter sampling either because of the restricted opportunity for sampling in 1952–53 or because the runs did not enter inshore waters until just before spawning.

Lower East Coast Population

The average percentage age composition of the lower east coast runs in recent years is presented in the following tabulation. Weighting of the age composition is to numbers of samples taken in the various statistical areas; the numbers of samples from the individual areas are roughly proportional to the commercial catches of the respective areas.

Season	In Year of Age								
	I	II	III	IV	V	VI	VII	VIII	IX
1949–50	+	1.5	66.7	26.9	4.1	0.6	0.1	+	0.0
1950–51	+	4.1	63.4	25.0	6.1	1.0	0.2	0.1	+
1951–52	+	6.6	57.5	27.1	7.0	1.3	0.3	0.1	+
1952–53	0.1	2.7	60.5	32.8	3.2	0.5	0.1	+	0.0

The relative contribution of each age-group in the catch has been remarkably similar in the past four years. Dominance has been held consistently by III-year fish. The same pattern of age distribution has been noted for each statistical area in which lower east coast herring are fished, and also in spawning samples (Table III). The similarity in age composition of the individual area catches on the lower east coast is in contrast to the considerable difference in age composition found in the more northerly and more southerly areas of the west coast of Vancouver Island stocks (Fig. 2). The reason for the general homogeneity of the various lower east coast fishing schools was discussed in the previous report of this series (Stevenson, Hourston, Jackson, and Outram, 1952, p. 66). It was pointed out that a single migration route was used in the passage of lower east coast herring from offshore summer feeding-grounds to inshore fishing areas, and that all runs tended to pass through each of the fishing areas. The west coast population, on the other

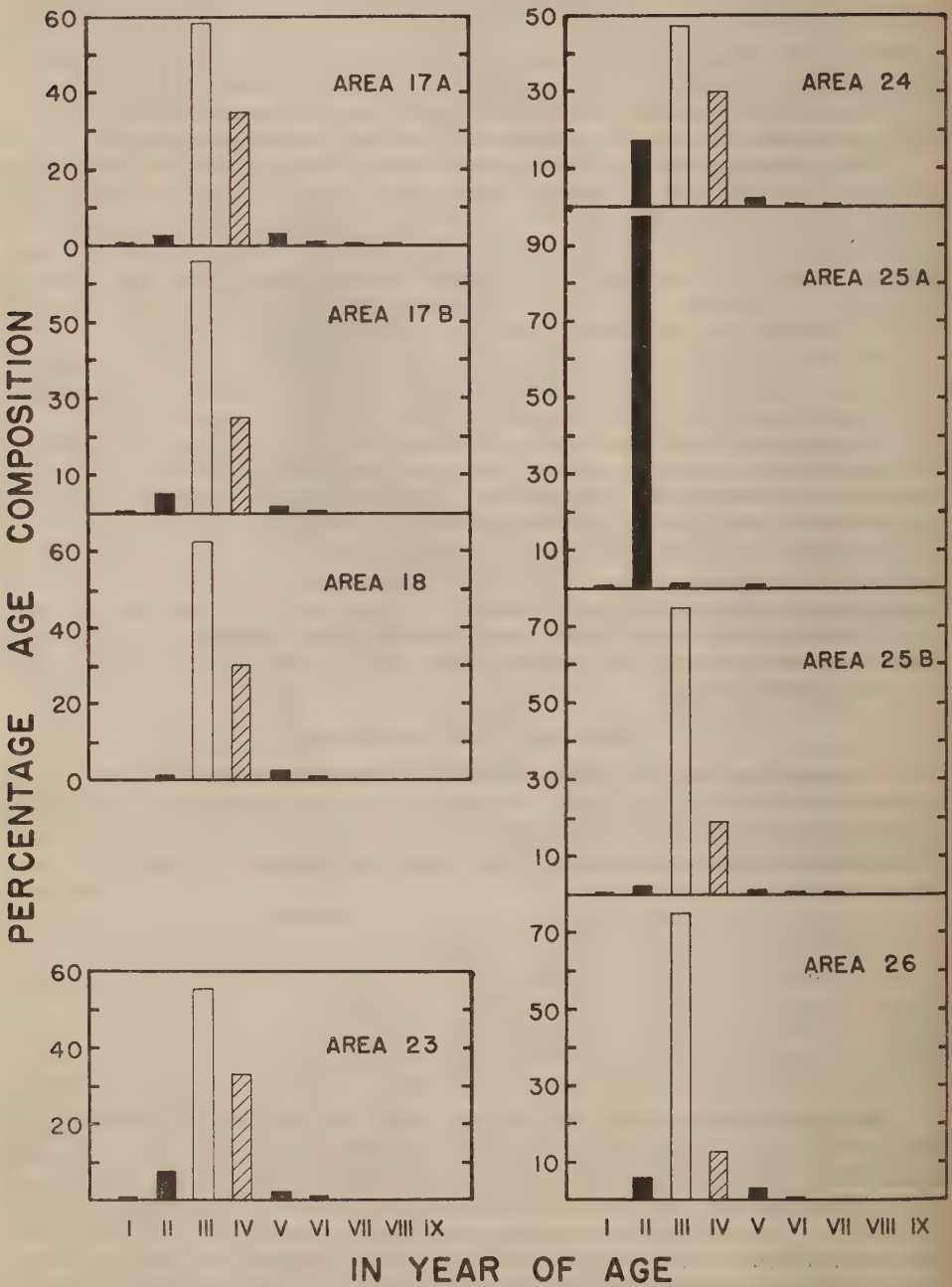


Fig. 2. Diagrams showing the average age composition in 1952-53 of herring in winter runs to the lower east coast of Vancouver Island (Areas 17A, 17B, and 18), and in winter runs to the west coast of Vancouver Island (Areas 23, 24, 25A, 25B, and 26).

hand, enters inshore waters by at least two distinct migration routes, and age-composition differences in these groups of fish presumably reflect a partial segregation of the population on the feeding-grounds.

The uniformity of the age composition of lower east coast stocks in recent years suggests that there is considerably less variation in year-class strength in the lower east coast population than in the west coast population. Information on differences in abundance of lower east coast year-classes can best be derived from catch data and extent of spawning. Catch data are sparse for 1952–53, but spawn deposition in the spring of 1953 shows a pronounced increase over that in 1952 (*see* section of this report on "Extent and Intensity of Spawning"). Although part of the increase in the spawning population was due to the decrease in catch in 1952–53, it appears that population abundance was greater than in the previous year. Hence, the dominant 1950 year-class (III's) is presumably of greater than average abundance.

Fish of Age II were less abundant than in the two preceding seasons. This suggests that the 1951 year-class may not be as strong as the 1950 year-class. However, abundance of II's has not been as reliable an indicator of year-class strength on the lower east coast as on the west coast.

Sex Ratio and Stage of Development

The sex ratio (number of females divided by number of males) and the sexual development of the herring in samples taken in the 1952–53 winter runs and the 1953 spawning runs are shown by area in Tables IV and V for the west coast and lower east coast populations respectively.

West Coast Population

Generally, males and females have been about equally represented in west coast winter runs, but males have been more numerous than females in spawning runs (Stevenson, Hourston, Jackson, and Outram, 1952). These conditions have been explained mainly by the tendency for females to live longer than males, and on the basis of differences in age composition between winter and spawning runs (the average age of the latter is usually less than that of the former). In 1952–53 the number of females exceeded the number of males in winter samples, largely as a result of the abundance of females in samples from Area 25. Possibly the winter sampling with regard to sex was inadequate in this area. On the other hand, the number of males was more numerous than usual in the spawning samples, especially in Area 25, but also in the more northerly west coast areas generally. This might suggest that males migrated inshore later than the females in the past season. The problem is extremely complex, and the data appear to warrant a detailed analysis in a separate report.

Immature fish were more numerous both in winter and spawning runs than in the previous year. The relatively high proportion of immature fish in the 1952–53 winter runs was largely due to inclusion of the samples from Area 25A, which were taken from unrecruited schools (over 98 per cent of the fish were of Age II). It is not clear why immature fish were so abundant in the spawning runs (2.6 per cent). Previously, immature fish have not accounted for more than 0.8 per cent of the individuals taken in spawning samples.

Lower East Coast Population

The sex ratio of fish in lower east coast winter samples (0.84) was about the same as that in the previous season (0.88). The males in winter samples of this sub-district are generally more abundant than females, while, as mentioned previously, the sexes are usually found in equal numbers in west coast winter runs. The generally younger average age of the lower east coast herring appears to be the reason for the greater representation of males.

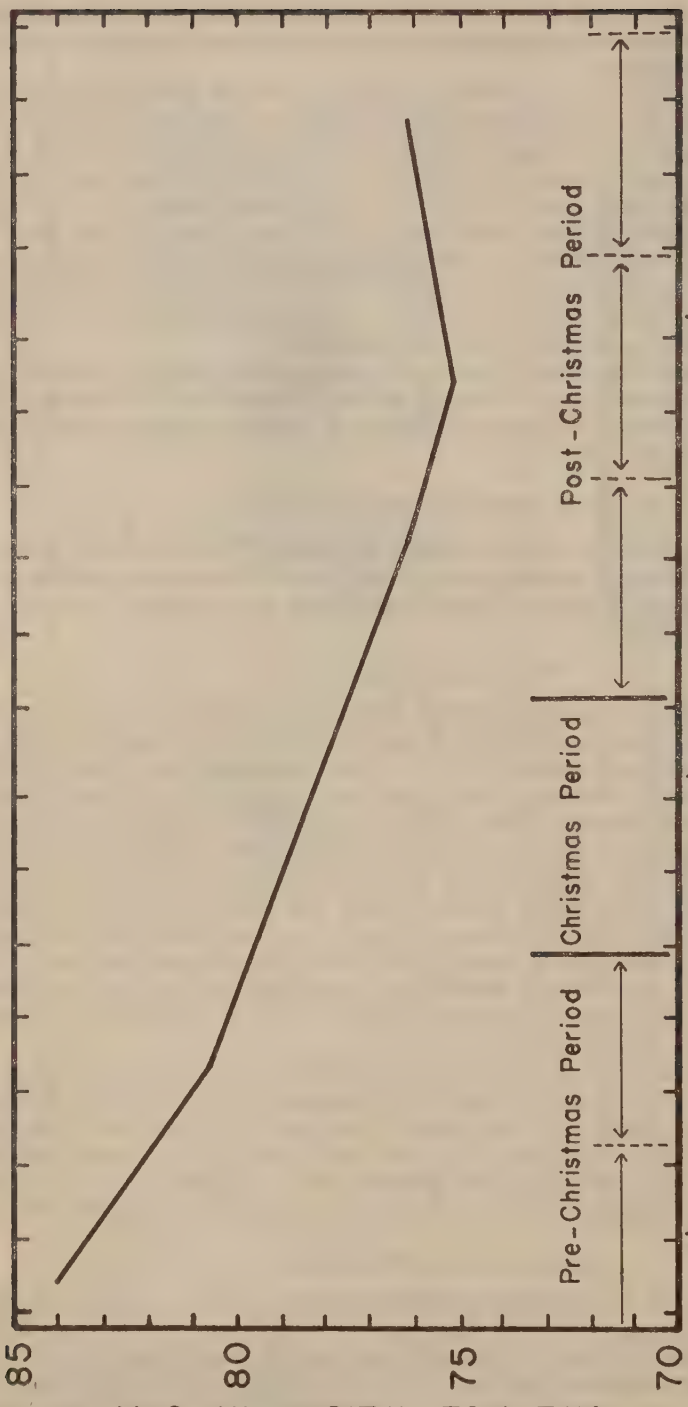


Fig. 3. Average weight of III-year herring in the 1952–53 lower east coast fishery; average weight is calculated for two pre-Christmas and three post-Christmas periods of the fishery.

Immature fish were less abundant on the lower east coast than in the 1951–52 season (Table V). This would be expected in view of the decreased abundance of II-year fish in 1952–53 as compared to the previous year.

The sampling of lower east coast spawning runs in 1952–53 was not sufficiently intensive to permit detailed analysis of sex ratio and development.

Average Length and Weight

Changes in average length and weight from year to year give information on possible differences which exist in environmental conditions (food-supply, temperature, etc.) which influence growth. The average lengths and weights of west coast herring in the 1952–53 winter runs are shown in Table VI, and average lengths of herring in the 1953 spawning runs are given in Table VII. Comparable data for the lower east coast fish are shown in Tables VIII and IX respectively.

In winter runs the average length of fish, at each age, was similar in each of the lower east coast areas, but the average weight of Area 18 fish was greater than that of either Area 17A or Area 17B fish. Fishing in Area 18 took place earlier in the season than fishing in the other two areas. The former fishery was finished by early December, while the latter fisheries continued into February. The growth data, therefore, show the loss in weight which the herring undergo during the winter, when feeding does not normally take place (Fig. 3).

The average length of spawning fish in Area 17B was appreciably greater at each age above II than that of spawning fish from Area 17A or Area 18, or than that of winter runs of any of the three areas. No explanation for this can be offered.

No significant differences were found in average length or in average weight of each age-group of winter-run fish in Areas 23, 24, 25B, and 26. However, herring taken in winter samples from Area 25A, mostly II-year fish, showed a significantly smaller size. Fish of Age II from Area 25A averaged 144 millimetres in length and 35 grams in weight, while fish of this age from other areas averaged 162 millimetres and 51 grams respectively. It appears that the Area 25A herring schools sampled were composed of fish that had not been recruited to the adult stocks. Presumably recruited II-year fish are exposed to better feeding conditions than unrecruited II's. Although the time when recruitment of II-year fish occurs is not known with certainty, it appears that it takes place sufficiently early in the summer to enable the new recruits to feed for part of the summer with the adults on offshore feeding-grounds. The unrecruited II's presumably feed in inshore localities, which are less productive in herring-food organisms. Another possibility, however, is that only the faster-growing II-year fish become recruited.

No explanation can be given to explain the generally great average size of each age-group in spawning runs of the more northerly west coast areas (Areas 25A, 25B, 26, and 27). The average lengths were similar to those found in the Area 17B spawning runs. The latter run, as mentioned earlier, contained fish that were large in comparison to the spawning runs of other lower east coast areas.

The average lengths and weights of herring in each population are given below for the major age-groups in the winter runs of recent years:—

Year	Lower East Coast Population					West Coast Population				
	II	III	IV	V	VI	II	III	IV	V	VI
Length in millimetres—										
1949–50	153	188	200	211	211	164	190	202	212	220
1950–51	153	188	200	211	220	158	188	204	215	220
1951–52	151	185	198	209	217	159	187	205	217	226
1952–53[1]	156	184	196	209	214	162	185	198	209	222
Weight in grams—										
1949–50	45	91	111	131	148	56	94	117	137	152
1950–51	42	91	113	137	150	50	88	114	135	149
1951–52	46	91	114	139	158	53	90	114	139	157
1952–53[1]	45	77	94	119	135	51	80	100	119	149

[1] In compiling the 1952–53 length and weight data for the west coast population, the Area 25A samples, composed almost entirely of slow-growing and apparently unrecruited II-year fish, were not included.

A striking reduction in average weight occurred in the 1952–53 winter runs of herring in both the lower east coast and west coast populations. All age-groups except II-year fish showed weight decreases, which varied from 14 to 18 per cent on the lower east coast and from 5 to 14 per cent on the west coast. Reasons to explain this decrease are obscure. The lack of a regular fishery in the winter of 1952–53 resulted in greatly increased spawning stocks in the spring of 1953, and it may be expected that growth during the summer of 1953 may be reduced because of competition for available food, but this would not account for the decreased growth that obviously occurred in 1952. The most likely possibility appears to be that the amount of suitable food organisms on the feeding-grounds in the summer of 1952 was unusually low. No direct evidence on this point is available.

The fact that the II-year fish (1951 year-class) maintained their usual weight suggests that they were not exposed to the poor feeding conditions. As pointed out previously, precise data on time of recruitment of II-year fish are lacking, but an inference may be made that a period of unfavourable feeding conditions commenced immediately after spawning in early spring and ended before the recruitment of II-year fish began.

No appreciable difference exists in the average lengths of lower east coast fish in 1952–53 and in the previous season. A decrease in average length of west coast fish of Age III and over is apparent, but the decrease is considerably less marked than that shown by average weight data.

EXTENT AND INTENSITY OF SPAWNING

The amount of herring-spawn deposited in the west coast and lower east coast sub-districts was estimated again in the spring of 1953.* As in the past years, two independent surveys of spawn depositions were carried out on the west coast—one by members of the herring-investigation staff and the other by fisheries officers. A single survey was undertaken in the lower east coast sub-district by fisheries officers. Methods used in the surveys were similar to those of previous years (Tester and Stevenson, 1948).

West Coast Population

The extent of spawn deposition on the west coast of Vancouver Island in the spring of 1953 was the greatest ever recorded. It was 80 per cent greater than in the previous year. Each statistical area showed increased spawn deposition over the previous year, and Areas 23 and 24 had the greatest spawn depositions of the past seven years. The smallest increase in spawn deposition in relation to the previous year's spawning was in Area 25, the area which showed a phenomenal increase in population abundance in 1950–51 and which since then has maintained high abundance through heavy recruitment and low exploitation (Stevenson, Hourston, Jackson, and Outram, 1952, p. 76).

A summary of the extent of west coast spawn depositions in the past seven years is given by statistical areas in the following tabulation, with intensity of spawn deposition in parentheses. Extent of spawn deposition is in statutory miles, and average intensity of spawn deposition is calculated by weighting the intensities of the individual spawnings—very light, light, medium, heavy, and very heavy—in the ratio of 1, 2, 3, 4, and 5 respectively.

* Lists of the individual spawning localities in the west coast and lower east coast sub-districts, with dates, intensities, and extent of spawn depositions, will be supplied on request (Supplementary Tables IV and V).

Area	1947	1948	1949	1950	1951	1952	1953
23	13.2 (3.3)	10.9 (3.0)	11.7 (3.1)	13.4 (2.4)	8.8 (2.9)	6.2 (2.6)	14.5 (2.1)
24	6.0 (3.6)	8.4 (3.3)	4.3 (3.1)	4.2 (2.8)	11.4 (1.3)	5.6 (2.3)	8.4 (2.6)
25	9.3 (3.8)	12.8 (3.0)	16.3 (3.5)	18.2 (3.2)	28.3 (3.4)	21.4 (3.7)	27.4 (3.8)
26	2.5 (2.9)	2.0 (2.8)	2.2 (3.4)	3.2 (3.3)	1.5 (3.4)	1.4 (2.8)	4.4 (3.0)
27	1.4 (2.7)	9.7 (2.2)	6.6 (2.6)	4.5 (3.0)	4.9 (3.1)	1.1 (3.2)	9.6 (3.6)
All areas	32.4 (3.1)	43.8 (2.7)	41.1 (3.2)	43.5 (2.9)	54.9 (2.9)	35.7 (3.3)	64.3 (3.2)

The average intensity of west coast spawning did not differ appreciably from that of the previous year. Intensity of deposition showed the greatest decrease in Area 23 and the greatest increase in Area 27. No change in intensity in any area approached in magnitude the pronounced increase noted in Area 24 from 1951 to 1952.

Considering both the extent and intensity data, the 1953 spawning population was the largest of recent years. The lack of a fishery in 1952–53 permitted an unusually great escapement. The abundance of the 1953 year-class in future years will be followed with especial interest. Valuable information should be forthcoming on possible relationships between amount of spawn and the magnitude of the eventual recruitment to the fishable population.

Lower East Coast Population

The amount of spawn deposited on the lower east coast also reached a record level. Spawning extent showed a phenomenal increase over that of the previous year (82.7 miles, as compared to 31.5 miles in 1952). Increased spawning occurred only in Areas 17A and 17B; the other lower east coast areas, which habitually account for a minor proportion of the spawning, showed reductions in spawn depositions when compared to spawnings of the previous year.

Average intensity of deposition increased markedly in 1953. In only one other year in the past seven years (1950) was spawning intensity as great as in the 1953 season.

In the following tabulation the extent of spawning on the lower east coast is given in statutory miles for each year since 1947; spawning intensities, determined on the same basis as those presented previously for the west coast of Vancouver Island, are shown in parentheses.

Area	1947	1948	1949	1950	1951	1952	1953
17A	1.5 (2.0)	5.7 (1.8)	3.6 (3.7)	6.6 (4.4)	12.7 (2.9)	8.7 (2.7)	15.5 (3.4)
17B	6.1 (4.3)	7.9 (3.2)	10.8 (3.9)	7.0 (3.4)	6.7 (2.6)	18.0 (3.4)	63.4 (3.9)
18	2.2 (2.2)	3.7 (2.5)	6.4 (3.0)	1.3 (1.7)	0.6 (1.3)	4.6 (1.3)	3.8 (2.0)
19	0.1 (2.0)	0.1 (1.0)	0.1 (1.0)	0.2 (1.0)	0.2 (1.0)	0.2 (1.0)	+ (—)
All areas	9.9 (3.4)	17.4 (2.6)	20.9 (3.5)	15.1 (3.7)	20.2 (2.7)	31.5 (2.9)	82.7 (3.7)

The striking increase in spawn deposition in each population poses the problem of determining the extent to which it was caused by the small 1952–53 catch, and the extent to which it may have resulted from increased population abundance. The percentage increase in lower east coast spawning (in relation to the spawning of the previous year) was about twice that of west coast spawning (163 per cent as compared to 80 per cent). The phenomenal increase in spawn deposition on the lower east coast occurred in spite of the fact that an appreciable catch was made in the immediately preceding fishing season (8,085 tons). On the other hand, a smaller increase took place on the west coast, where a negligible commercial catch occurred (about 20 tons). If it were assumed that population abundance was approximately equal in both populations in 1951–52, population abundance must have been considerably greater on the lower east coast in 1952–53 than on the west coast. It is obvious that the confidence that can be placed in this statement depends upon knowledge of fluctuations in abundance in previous years.

In the following section of the report, data pertaining to population abundance in 1952–53 are discussed, and in the section entitled "Catch, Spawn, and Abundance," the general relationship between catch, spawn deposition, and population abundance is analysed, using data accumulated since the beginning of the present detailed investigation of the two populations.

POPULATION ABUNDANCE IN 1952–53

The seventh year of the comparative study of the herring populations of the west coast and lower east coast of Vancouver Island provided little data on the main purpose of the investigation; namely, to determine the merits of contrasting systems of fisheries management. Inability of fishing companies and fishermen to come to agreement on fishing prices prevented normal operations of the herring-seining fleet. As a result, two basic requirements for the scientific experiment were not met in 1952–53: (1) West coast fishing was not unrestricted—a negligible amount of herring was taken in west coast waters—and (2) the fixed quota of 40,000 tons was not taken on the lower east coast; although it appeared highly likely that there were sufficient fish to enable this to be done, only about 20 per cent of the quota was caught.

The lack of fishing on the west coast population in 1952–53 prevented assessment of the effects of non-quota fishing on lowered population abundance. In 1951–52 the first major reduction in population abundance occurred on the west coast since the beginning of the present intensive study—a decrease apparently not caused through the effect of fishing, but by the relatively poor recruitment of the 1948 and 1949 year-classes (Stevenson, Hourston, Jackson, and Outram, 1952). Results of investigation up to 1951–52 suggested that during periods of generally high population abundance, removal of quota restriction on catch would not decrease the spawning population to a level at which future recruitment was impaired, as long as a closure date prior to spawning is maintained. An important question which remained to be solved concerned the effect of non-quota fishing during a period of low year-class recruitment and, hence, low abundance. Lack of fishing, however, prevented accumulation of data in 1952–53 pertinent to this problem.

A second consequence of the absence of a fishery was the lack of opportunity to obtain catch statistics data comparable to those of previous years, from which assessment of relative population abundance could be made. Interpretation of information on percentage age composition in terms of population abundance requires both catch and spawn data. Also, the previous use of spawn data in the determination of relative population abundance was based on the existence of approximately equal annual catches.

Certain data are available to assist in determining recent changes in the abundance of the two populations, but the conclusions derived from them are less reliable than those of former years. One of the two seiners that fished for a saltery on the lower east coast submitted catch records that showed an average availability of 107 tons per day's fishing. This availability figure is high in comparison with those of previous fishing seasons, but since it was based on records of only one vessel, and since only six vessels participated in the fishing, compared to many times that number in previous years, only limited confidence can be placed in its indication of the abundance of fish. For the first time, trawlers caught an appreciable amount of herring in the lower east coast in 1952–53. Undoubtedly, improvement in gear and the growing experience of trawl captains in fishing for herring were large factors in enabling the taking of over 300 tons of herring by trawl. In addition, the lack of competition with seines was presumably an advantage to the trawlers. However, it is apparent that successful trawling for herring requires appreciable quantities of herring on the fishing-grounds. Considering these sketchy indications of abundance, along with the phenomenal increase in spawn depositions on the lower east coast in the spring of 1953, it appears that the lower east coast stocks were at least as abundant and probably more abundant than in the previous year.

The almost complete absence of fishing on the west coast precludes a direct comparison of abundance in that population in 1952–53 and in the previous year. Spawn deposition increased greatly over that of the preceding year (from 35.7 to 64.3 miles), but the amount of fish taken decreased from 30,000 tons to a negligible 20 tons. The question is whether 30,000 tons of herring are equivalent to an amount of fish represented by the difference (28.6 miles) in spawn deposition (in which case population abundance would be about equal in the two years), whether it is more than equivalent (in which case abundance decreased), or whether it is less than equivalent (in which case abundance increased). The only evidence that can be applied to the problem is given through analysis of the 1949–50 and 1950–51 data (Stevenson, Hourston, and Lanigan, 1951). In those years, population abundance was considered to be about equal. Catch decreased from 1949–50 to 1950–51 by 12,000 tons, while spawning increased 11 miles. On this basis, a decrease in catch of nearly 30,000 tons, such as occurred in 1951–52 and 1952–53, would be balanced by an increase in spawning of 27 miles if population abundance were about the same in the two years. The fact that spawning in 1953 actually increased by 29 miles suggests that population abundance in 1952–53 was equal or perhaps slightly greater than in the previous year.

CATCH, SPAWN, AND ABUNDANCE

Changes in population abundance between consecutive years have been analysed qualitatively over the period of the present study, and these changes have been discussed in the present series of reports. The analysis has been based primarily on known changes in catch and spawn deposition. If, for example, catch were greater in one year than in the preceding year, and if the spawn deposition remained about the same, it would be concluded that the abundance in the population under consideration increased. Refinement of this general approach will now be attempted in an effort to obtain quantitative information on abundance of the two Southern British Columbia populations in recent years.

Population abundance, as considered in this discussion, is the abundance of a population that would exist at spawning-time if no catch had been taken. According to this definition, it is therefore equal to total abundance of the adult stocks at the start of the fishing season less the natural mortality occurring beween the commencement of the fishery and the time of spawning, providing that no recruitment takes place during this period.

The total population abundance, as previously defined, can be considered to consist of two components: (1) The amount of fish in the catch that would survive until spawning if no fishery had taken place, and (2) the amount of fish that spawned. This relation can be expressed by the equation $P=Cs+Sx$, where P is total population abundance as previously defined (in numbers of fish), C is catch (in numbers of fish), s is survival rate of the fish in the catch from time of fishing until spawning time, S is amount of spawn deposited on the spawning grounds (in statutory miles), and x is the number of fish which spawn in a statutory mile of spawning beach.

The number of fish in the catch that would survive till spawning-time if no fishing had taken place is represented in the equation by Cs. C can be readily calculated by dividing original catch figures (given by weight) by average weight of fish of all ages caught in the fishery. Precise data are lacking to provide information on the value of s, but considering the short period of time elapsing from time of fishing until spawning it seems likely that survival is high. For present purposes the value of s will be regarded as 1. Hence Cs is considered equal to C.

Sx in the equation represents the number of fish that spawn. S is the number of miles of spawn recorded by fisheries officers and herring investigators in annual surveys of the spawning-grounds. The original records are subjected to two modifications:

(1) Corrections are made for differences in average spawning intensity from year to year by computing the amount of spawn on the basis of a standard spawning intensity of 3,* and (2) corrections are made for incompleteness of coverage of spawning-grounds; using all information available,† it is thought reasonable to assume that west coast spawning-grounds have undergone about 85 per cent coverage in each year of the present study, and that lower east coast spawning-grounds have had about 75 per cent coverage in the years 1947 to 1952 and about 90 per cent coverage in 1953.

Values for C and S are given for the west coast and the lower east coast populations in each of the past seven years in Tables X and XI respectively, and the value of s is taken as unity. Hence, x is the only factor whose value must be determined before P can be calculated in the equation $P=Cs+Sx$.

As an aid to ascertaining the correct value of x, various values of x can be substituted into the equation. Since C and S are known for each year in each population (Tables X and XI), and since s is constant, a linear relation is obtained between P and x. Thus, on the west coast in 1946–47, C is 5.42, S is 39.4, s is 1, and therefore $P=5.42+39.4x$. This straight line is shown in Fig. 4 (A), together with lines representing the data for other years of the period. In Fig. 4 (B), lines of each year are plotted, using comparable lower east coast data. It will be noted, through reference to the generalized straight-line equation $y=a+bx$, that the catch (C or, more strictly, Cs) is represented by the intercept on the y-axis, while the spawn deposition (S) is represented by the slope of the line.

Qualitative information on changes in total west coast abundance from year to year, which was given in previous reports of this series, can be used in fixing the value of x:—

(1) Total abundance in 1947–48 was considered to be less than in 1946–47 (Tester and Stevenson, 1948).

(2) Abundance increased in 1948–49 over that in 1947–48 (Stevenson, 1950).

(3) Abundance in 1949–50 remained generally high (Stevenson and Lanigan, 1950), but decreased catch and slightly reduced spawn deposition indicated a somewhat lessened abundance in relation to the previous year.

(4) Abundance in 1950–51 was considered to be approximately the same as in the previous year (Stevenson, Hourston, and Lanigan, 1951).

(5) Abundance in 1951–52 showed a sharp decrease over that of the previous year (Stevenson, Hourston, Jackson, and Outram, 1952).

(6) It was stated in a previous section of this report that population abundance in 1952–53 was as great as in the previous year and possibly greater, but this was based on less detailed data than in previous years because of the greatly reduced fishery resulting from the fishermen's strike.

These statements permit setting limits on the possible value of x. If statement (1) is correct, the value of x cannot be greater than about 0.19×10^8, the point at which the 1946–47 and 1947–48 lines cross; that is, the point at which population abundance is equal for each year. Statement (6) indicates that the value of x cannot be less than about 0.07×10^8 (the point at which the 1951–52 and 1952–53 lines cross). The value of x must therefore lie between 0.07×10^8 and 0.19×10^8. Statement (4) suggests that x is about 0.09×10^8.

* In spawn surveys the number of eggs on a unit area of substrate is estimated, and the intensity of spawn deposition is categorized as very light, light, moderate, heavy, or very heavy. Several such estimates are made for each individual spawning-ground, and an average intensity is assigned to it. Average intensity for the spawnings in a statistical area or for the spawnings in a sub-district (the whole area of a population) is determined by weighting the extent of each individual spawning by 1, 2, 3, 4, or 5, depending on the category of intensity assigned. Converting from calculated intensity to standard intensity of 3 is accomplished by multiplying the extent of spawn by the ratio of the calculated intensity to 3. Thus, 1 mile of spawn with calculated average intensity of 2.7 is considered equal to 0.9 miles with average intensity of 3.

† Information used to estimate completeness of coverage of surveys include (*a*) fisheries officers' remarks on spawning reports pertaining to this subject, (*b*) knowledge of differences in ease of discovering the spawn depositions in different areas, (*c*) size of areas surveyed by various fisheries officers, (*d*) the fact that the west coast areas are surveyed by herring investigators as well as fisheries officers, and (*e*) the greater opportunity on the lower east coast for fisheries officers to receive information from the public on the occurrence of herring spawnings.

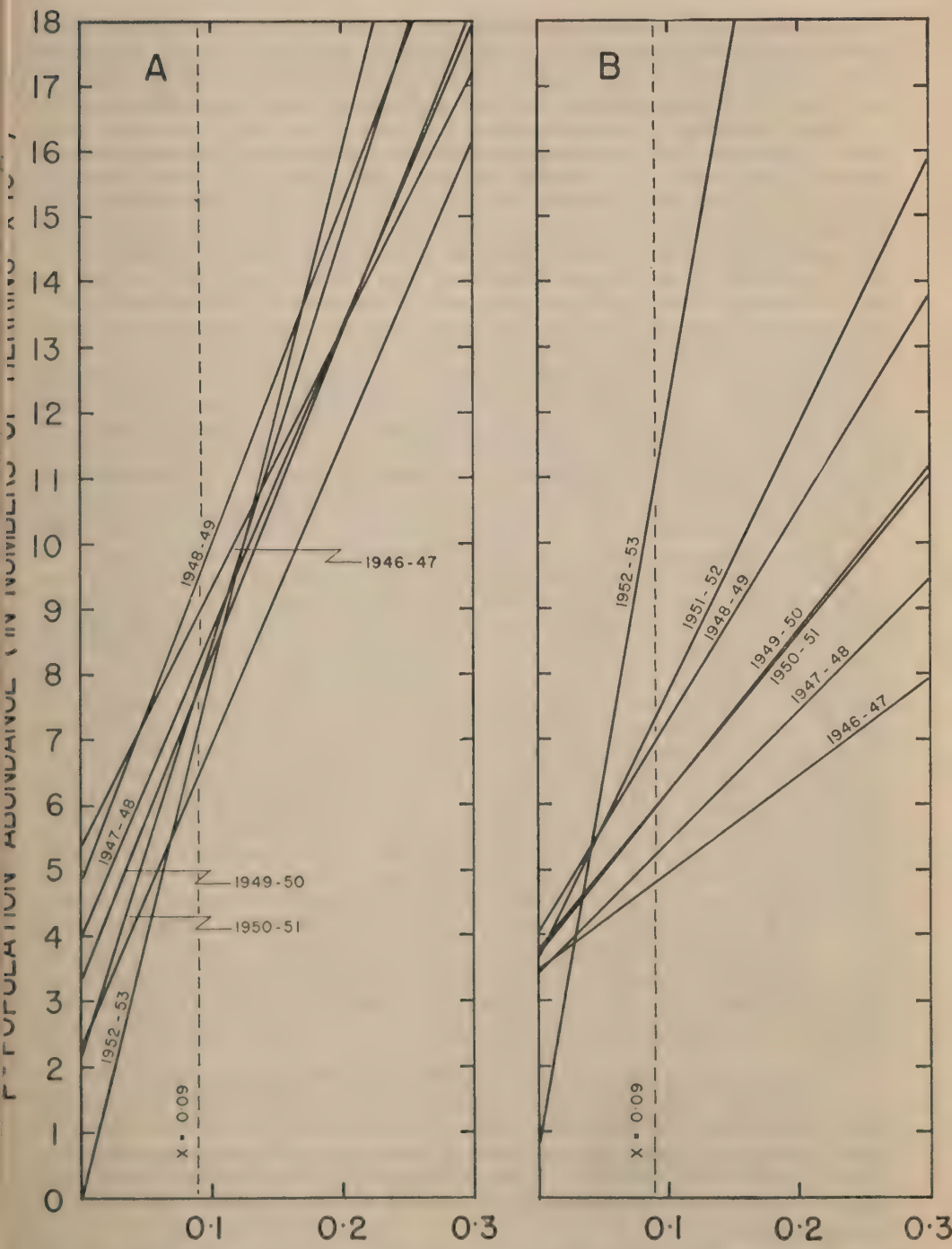


Fig. 4. Total population abundance (in number of fish $\times 10^8$) at spawning-time if no fishery had taken place (P) plotted against number of herring ($\times 10^8$) that spawn in a statutory mile of spawning-ground (x) on the west coast of Vancouver Island (A) and on the lower east coast of Vancouver Island (B) for each of the past seven years.

Hourston's (1953) data on the number of eggs and number of herring involved in the northern sub-district spawning of 1952 indicated that 0.08×10^8 fish deposit an average mile of spawn.* The similarity between the two estimates, each of which was determined by a different method, gives some confidence in the accuracy of the estimates.

Similarly, limits of x can be determined for the lower east coast data. In previous reports of this series, it was concluded that population abundance on the lower east coast increased from 1946–47 to 1947–48, increased again from 1947–48 to 1948–49, decreased from 1948–49 to 1949–50, and increased each year from then until 1951–52. A further increase in abundance probably occurred from 1951–52 to 1952–53 (discussed in an earlier section of this report). Using the knowledge of increased abundance from 1951–52 to 1952–53 and increased abundance from 1949–50 to 1950–51,† it will be observed from Fig. 4 (B) that the value of x must lie between 0.04×10^8 and 0.10×10^8. Since this range contains 0.09×10^8, the value taken for west coast data, it appears reasonable to apply this value to both populations.

Consideration should be given to whether a constant value of x can be applied to all years of the study. Two factors could possibly cause annual variations in x: Changes in average age of the spawning population (and, hence, variation in average number of eggs deposited per female), and changes in average width of spawn deposition. Neither factor, however, appears to warrant the use of different values of x in different years. It has been calculated that annual changes in average age of the west coast population in recent years would rarely alter the value of x more than 7 per cent. On the lower east coast, changes in average age have been almost negligible for the past several years.

Considerable variation has been recorded in average width of spawnings from year to year, but there is considerable doubt that these differences reflect proportional changes in the value of x. The accurate assessment of the average width is extremely difficult because of a number of factors: (1) The outer margin of a spawning is usually extremely irregular, requiring much surveying to determine average width; (2) the fact that the outer edge of the spawning is under water necessitates use of dragging equipment to determine the outer margin, and no equipment has been devised which will effectively retrieve all types of substrate on which spawn is deposited; (3) patches, often of considerable area, are sometimes found within a spawning area bearing no spawn, making very detailed surveys of the spawning-ground necessary for accurate determination of average width; (4) the distance from the outer margin of a spawning to the inner margin on shore is usually largely over water even at low tide, and measurement of this distance must therefore be estimated more or less by sight and without recourse to a system of precise measurement (many possibilities of errors in personal judgment are thereby involved in assessing width of spawnings); and (5) sufficient time is never available to fisheries officers or to herring investigators to determine with even moderate accuracy the average width of all spawnings. Tester (1948) discussed the comparative accuracy of the spawning index based on length of spawn deposition and that based on length combined with width (area). He concluded the former was probably just as accurate as the latter.

The same value of x can perhaps be applied to both the lower east coast and west coast populations. The average age of lower east coast herring is usually less than that of west coast herring, but the resulting increase in the value of x on the lower east coast would generally be small. Average width of spawnings on the lower east coast are usually less than on the west coast. If this difference is real, it would tend to give a lower value of x for the lower east coast, and tend to nullify the effect of average age differences in the two stocks.

* A correction was applied to Hourston's data to correct for the fact that the northern herring in 1952 had a much greater average age and larger average size (therefore, greater fecundity) than ever found in herring of the Southern British Columbia populations.

† Any difference in lower east coast population abundance in 1949–50 and 1950–51 seems overshadowed by similarity in abundance for those years at all values of x (Fig. 4 (B)). Thus, less confidence should probably be put in the accuracy of the upper limit of the range than of the lower limit.

Substituting data given in Tables X and XI into the equation, population estimates (in numbers of fish $\times 10^8$) can be made for the lower east coast and the west coast in each year. These are presented in the following tabulation, with exploitation rates, calculated as the ratio of catch to total population, in parentheses:—

Year	Lower East Coast	West Coast
1946–47	4.84 (0.72)	8.97 (0.60)
1947–48	5.25 (0.66)	8.26 (0.49)
1948–49	7.00 (0.58)	9.50 (0.51)
1949–50	5.96 (0.63)	7.84 (0.43)
1950–51	5.97 (0.63)	7.90 (0.29)
1951–52	7.40 (0.51)	6.51 (0.36)
1952–53	11.06 (0.08)	7.26 (+)

No statistically significant relationship exists between the fluctuations in the abundance of the two stocks over the seven-year period (Fig. 5). Factors that affect year-class strength apparently show no consistency in their action upon the two populations over a number of years. From 1946–47 to 1950–51, population abundance on the west coast exceeded that on the lower east coast, and the difference in abundance was fairly constant during this period. This suggests that at that time year-class recruitment in each stock fluctuated similarly. Since 1950–51, lower east coast abundance was greater than abundance on the west coast, resulting primarily from differential recruitment of the 1949 and 1950 year-classes in the two populations.

The lower east coast catch has comprised a larger proportion of the population than the west coast catch in each year of the investigation. The lower east coast quota has accounted for between one-half and three-quarters of the total population each year, while unrestricted fishing on the west coast (until the official closure date) attained a comparable degree of exploitation in only one season (1946–47). The greater exploitation of the lower east coast stocks suggests that the lower east coast population is more completely available to the fishing fleet than the west coast population is. There seems to be little doubt that the low exploitation on the west coast* in 1949–50, 1950–51, and 1951–52 was largely a result of the natural limitations on catch imposed by late inshore migration of Area 25 runs (Stevenson, Hourston, Jackson, and Outram, 1952, p. 79). Even lower exploitation would have occurred in 1951–52 if the fishing closure date had not been extended in Area 25. The high exploitation on the lower east coast is undoubtedly connected with the simple pattern of inshore migration to the lower east coast fishing localities (Stevenson, Hourston, Jackson, and Outram, 1952, p. 66). Fishing can take place in almost any part of the lower east coast, and the area encompassed by lower east coast waters is small in relation to the area of inshore waters on the west coast.

It seems certain that exploitation rates considerably higher than those shown would be attained on the lower east coast if the catch quota were removed. There is abundant evidence that further catches could have been made each year on the lower east coast after the quota was reached. A distinct possibility exists that removal of the lower east coast quota could result in such high exploitation that the spawning stock would be reduced to a level at which future population abundance could not be maintained. At the present rate of exploitation there is evidence of a tendency for year-class strength to be

* Exploitation rates of the west coast population have been independently calculated from magnet recovered tag returns for the seasons from 1946–47 to 1950–51: 0.32 (1946–47), 0.76 (1947–48), 0.64 (1948–49), 0.26 (1949–50), and 0.18 (1950–51). Although detailed analysis of sources of error involved in these determinations has not been made, the accuracy of these estimates is probably less than those calculated by the method developed in this report. The most accurate determinations made from tag recovery are probably those for 1948–49, 1949–50, and 1950–51. During this period the exploitation rates showed a decrease by both methods of estimation. The differences between estimates derived by the two methods may be partly a result of the difference in time at which population abundance was computed. In the method discussed in this paper, exploitation rate is the ratio of the catch to the population abundance which would exist at spawning time if no fish were caught. In the tag recovery method, the population abundance is that existing at the beginning of the season before fishing begins. Although natural mortality is probably relatively low in the winter, this difference in time of computing population abundance would doubtless affect the exploitation estimations.

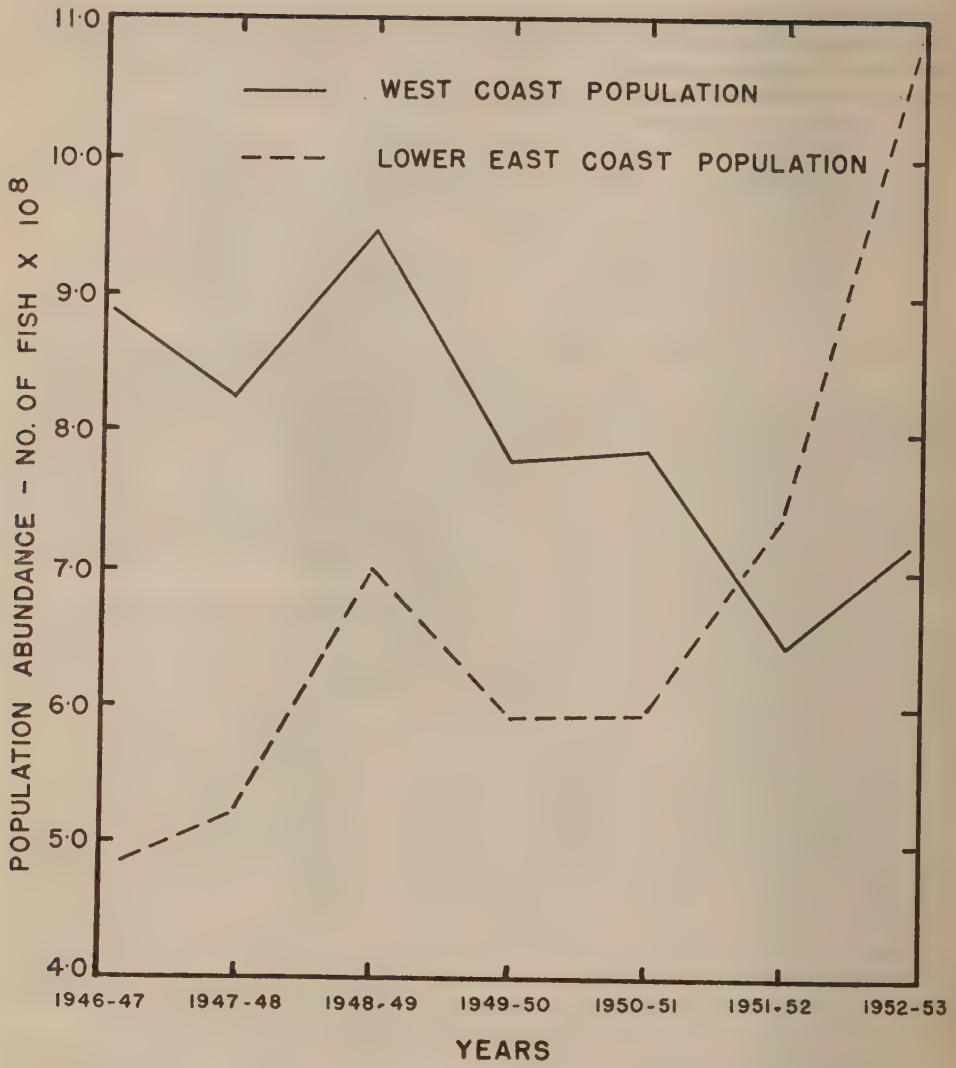


Fig. 5. Fluctuations in herring abundance (in number of fish $\times 10^8$) on the west coast and lower east coast of Vancouver Island in the past seven years.

directly related to the amount of spawn deposited (Stevenson, Hourston, Jackson, and Outram, 1952, p. 78). If this indication should be accurate, greater exploitation may impair future production.

On the other hand, restriction of fishing on the west coast by catch quota appears unnecessary to maintain an adequate spawning stock. In recent years the removal of quota regulations has apparently been accompanied by lower exploitation than that reached on the lower east coast, where a quota is applied. Furthermore, spawn deposition shows no relationship to future recruitment. Whether or not natural restrictions on catch would continue to limit exploitation on the west coast during a period of generally low population abundance is not known. When data can be obtained to answer this question, the main objective of the current investigation on these two herring populations will be attained.

SUMMARY

Collection of data relative to the comparative study of the west coast and lower east coast herring populations was hampered in 1952–53 by the greatly reduced catch resulting from failure of fishing companies and union to reach a price settlement. Only about one-fifth of the 40,000-ton lower east coast quota was caught (mostly taken for salting by special agreement), and a negligible quantity of herring was taken from the quota-free west coast population. In 1951–52, west coast abundance was sharply reduced from the abundance level of previous years, and the abnormally small catch in 1952–53 prevented studying the effect of non-quota fishing on lowered abundance.

The salt-herring operations on the lower east coast permitted normal sampling of the winter runs of that sub-district, but sampling of west coast winter runs was accomplished through the borrowing of fishing-vessels from the industry. The 1950 year-class (III-year fish) comprised almost two-thirds of the winter runs of each population. On the west coast it was considered that the recruitment from this year-class was average or slightly greater than average in relation to year-class recruitment of recent years. On the lower east coast it appeared that its recruitment was above average. The more northerly west coast runs (in Areas 25B and 26) showed a greater reliance upon this year-class than the runs to the more southerly west coast areas (Areas 23 and 24), whereas a striking uniformity in the proportion of fish belonging to this year-class was apparent in the runs to each of the lower east coast areas (Areas 17A, 17B, and 18). The 1949 year-class (IV-year fish) comprised slightly less than one-third of the winter runs in both populations. Age composition of spawning runs closely resembled that of the winter runs in both stocks, the only major difference being that the 1951 year-class (II-year fish) was generally better represented in lower east coast winter runs than spawning runs, but relatively more abundant in west coast spawning runs than winter runs.

A striking reduction in average weight of herring, at all ages except Age II, occurred in both populations in 1952–53 as compared to the previous year. Apparently feeding conditions in the summer of 1952 were less favourable than in the summer of 1951.

Spawn deposition in the spring of 1953 showed an increase of 163 per cent on the lower east coast over that of the previous year, and an increase of 80 per cent on the west coast. Part of the increase was undoubtedly caused by the absence of a regular winter fishery. Lack of catch statistics data comparable to those of other years made assessment of population abundance in relation to abundance in the previous year difficult. Using all available information pertaining to population abundance, it was concluded that the abundance of each population was at least as great as in the previous year and possibly greater. There was more evidence, however, of an appreciable increase in lower east coast stocks than in west coast stocks.

The qualitative method of estimating population abundance using data on catch and spawn deposition was put on a quantitative basis. The chief difficulty encountered was deciding upon the number of fish involved in a statutory mile of spawning. This value

was fixed by careful analysis of the qualitative information on population abundance that has been obtained since the beginning of the present study. Fluctuations in abundance of the two populations during the seven-year period of the investigation show no statistically significant relationship. Relatively heavier year-class recruitment in the past two years has increased lower east coast abundance above that of the west coast for the first time in the present study.

Exploitation has been consistently heavier on the lower east coast than on the west coast in spite of the catch quota regulations applied to the former sub-district. The low west coast exploitation is partly attributable to natural limitations to catch imposed by late inshore migration of runs to Area 25. Argument is advanced that some type of restriction may always be required on lower east coast catch (in addition to the official closing date prior to spawning) to maintain sustained production, whereas such restriction may not be required on the west coast. A major question which remains to be answered concerns whether or not catch restrictions are required on the west coast during a period of generally low abundance.

ACKNOWLEDGMENTS

The herring investigation thanks the fishing companies, herring-fishermen, and government fisheries departments for their indispensable support of herring research during 1952–53.

Special thanks are extended to the fishing companies for generously providing vessels on a charter-free basis. British Columbia Packers Limited lent the *Southisle* to enable sampling of the various winter herring runs, and the loan of this vessel was extended for participation in the spring tagging programme. In addition, this company provided the *Dominion No. 1* for a survey of spawning-grounds on the west coast of Vancouver Island. Nelson Brothers Fisheries Limited provided the *Western Ranger* for the sampling of winter herring stocks in December, and the *Western Commander* for sampling during January and early February. They also permitted the latter vessel to be used for tagging from late February to early April. Canadian Fishing Company Limited lent the *Ocean Pride* for use in the tagging programme. The conscientious efforts of the captains and crews of these vessels are also gratefully acknowledged.

The herring investigation is also deeply indebted to the captains and crews of seining and trawling vessels, and to workers in various herring-processing plants, for providing samples from the small 1952–53 catch.

The Federal Department of Fisheries again undertook the surveying of herring-spawning grounds in all coastal areas, through the efforts of its fisheries officers, and provided detailed information on catch. For these services, and for numerous other courtesies shown by the Chief Supervisor, A. J. Whitmore, and by the regional supervisors, H. E. Palmer and G. S. Reade, the investigation is deeply grateful.

The continued interest shown by the Provincial Department of Fisheries and its Deputy Minister, G. J. Alexander, in herring research is much appreciated. The Department has published annual reports of herring research continuously for seventeen years.

Sincere appreciation is extended to the staff members of the herring investigation for their conscientious efforts and for the co-operative spirit they have consistently shown. The junior author of this report, D. N. Outram, assistant scientist, supervised the spawn studies, which included those reported here and others concerned with spawn mortality. A. S. Hourston, assistant scientist, although concerned mainly with investigation of survival of juvenile herring, provided valuable advice on all phases of the research.

G. T. Taylor compiled and analysed data relating to catch, and acted as administrative assistant of the herring investigation. R. S. Isaacson and M. Bakich, laboratory technicians, were responsible for making age determinations of all fish sampled from the fishery and spawning runs. Mr. Isaacson also supervised the compilation of the age and growth data and assisted in many ways in the assembling of this report. Mr. Bakich continued the study of the structure and types of herring-scales.

All staff members assisted at one time or another in the field work of the investigation. A. G. Paul, senior field technician, undertook major responsibilities in the tagging and sampling programmes and in the maintenance of nets and various equipment. Other members of the technical staff, J. A. Bond, J. S. Rees, E. W. Stolzenberg, and B. Wildman, assisted in field programmes and in preliminary analysis of data. Miss Mary Cairns and Miss Diane Blackburn efficiently carried out stenographic and clerical duties.

Various other members of the staff of the Pacific Biological Station rendered valuable assistance to the herring investigation. M. A. Pirart, of the Electronics Laboratory, carried out developmental work on the operation of tag-detectors. R. M. Wilson and W. G. St. Clair, port contact-men in Vancouver and Prince Rupert, respectively, arranged with fishermen and plant personnel for the procurement of samples from herring landings in those ports.

Thanks are due to Dr. K. S. Ketchen and F. H. C. Taylor, associate scientists of the Pacific Biological Station, for constructive criticism of this report.

Lastly, it is a sincere pleasure to acknowledge the valuable advice and sympathetic encouragement offered by Dr. J. L. Hart, Director of the Pacific Biological Station, throughout the past year.

REFERENCES

HOURSTON, ALAN S. (1953): Estimation of herring population size by means of echo-sounder tracings and its application to herring research. Pacific Biological Station Circular No. 26, pp. 1–26. (Multilithed.)

STEVENSON, J. C. (1950): Results of the west coast of Vancouver Island herring investigation, 1948–49. Rept. British Columbia Fish. Dept., 1948, pp. 37–85.

——— (1953): The implications of the absence of the 1952–53 herring fishery on herring research. Pacific Biological Station Circular No. 27, pp. 1–22. (Multilithed.)

STEVENSON, J. C., and LANIGAN, J. A. (1950):* Results of the west coast of Vancouver Island herring investigation, 1949–50. Rept. British Columbia Fish. Dept., 1949, pp. 41–80.

STEVENSON, J. C.; HOURSTON, A. S.; and LANIGAN, J. A. (1951):* Results of the west coast of Vancouver Island herring investigation, 1950–51. Rept. British Columbia Fish. Dept., 1950, pp. 51–84.

STEVENSON, J. C.; HOURSTON, A. S.; JACKSON, K. J.; and OUTRAM, D. N. (1952):* Results of the west coast of Vancouver Island herring investigation, 1951–52. Rept. British Columbia Fish. Dept., 1951, pp. 57–87.

TESTER, A. L. (1948): The efficacy of catch limitations in regulating the British Columbia herring fishery. Trans. Roy. Soc. Can., Vol. XLII, Section V, pp. 135–163.

TESTER, A. L., and STEVENSON, J. C. (1947): Results of the west coast of Vancouver Island herring investigation, 1946–47. Rept. British Columbia Fish. Dept., 1946, pp. 42–71.

——— ——— (1948):* Results of the west coast of Vancouver Island herring investigation, 1947–48. Rept. British Columbia Fish. Dept., 1947, pp. 41–86.

* Reprints were published in year following the date of publication of report.

TABLES

Table I.—Catch (in Tons) Taken on the Lower East Coast and West Coast of Vancouver Island in 1952–53 According to Method of Fishing and Method of Disposal

Areas	Total Catch	Catch According to Disposal			Catch According to Fishing Method	
		Salted	Reduced	Bait[1]	Seine	Trawl[2]
Lower East Coast of Vancouver Island						
Area 17A	7,630	6,000	400	1,230	7,525	105
Area 17B	390	130	230	30	150	240
Area 18	65	.....	65	.....	.....	65
Totals	8,085	6,130	695	1,260	7,675	410
West Coast of Vancouver Island						
Area 24	20	.....	.....	20	20	.....

1 Including small amounts of herring that were canned, kippered, or sold fresh.
2 Including small amounts of herring that were taken by gill-net.

Table II.—Average Percentage Age Composition of Samples from the Winter and Spawning Runs to the West Coast of Vancouver Island during the 1952–53 Season

WINTER RUN

Area	No. of Samples	In Year of Age								
		I	II	III	IV	V	VI	VII	VIII	IX
23	25	0.08	7.77	56.48	33.16	1.94	0.56	.....	.....	.....
24	3	.....	18.18	48.82	30.30	2.02	0.34	0.34	.....	.....
25A	3	0.33	98.33	1.00	.....	0.33	.....	.....	.....	.....
25B	9	0.33	2.71	75.65	19.73	1.02	0.45	0.11	.....	.....
26	3	.....	6.40	75.76	13.80	3.37	0.67	.....	.....	.....
All[1]	40	0.12	7.31	61.66	28.47	1.85	0.53	0.05	.....	.....

SPAWNING RUNS

23	14	0.14	13.13	49.68	33.23	2.79	0.74	0.22	0.07	.....
24	4	.....	37.16	43.12	15.93	1.77	2.02	.....	.....	.....
25A	4	.....	7.92	43.34	31.30	8.20	7.18	1.53	0.26	0.26
25B	4	.....	0.76	45.10	21.28	14.90	15.19	2.02	0.76	.....
26	4	.....	0.76	65.34	26.54	5.58	1.53	0.25	.....	.....
27	2	.....	1.53	58.91	22.83	10.65	4.56	1.01	0.51	.....
All	32	0.06	11.66	50.03	27.84	5.69	3.85	0.64	0.19	0.03

1 Samples from Area 25A not included in these averages.

Table III.—Average Percentage Age Composition of Samples from the Winter and Spawning Runs to the Lower East Coast of Vancouver Island during the 1952–53 Season.

WINTER RUN

Area	Number of Samples	In Year of Age							
		I	II	III	IV	V	VI	VII	VIII
17A	72	0.15	2.14	58.22	35.35	3.45	0.58	0.07	0.04
17B	20	0.05	4.95	67.70	24.60	2.35	0.35	——	——
18	8	——	1.57	63.34	30.77	3.63	0.69	——	——
All	100	0.12	2.65	60.53	32.83	3.25	0.54	0.05	0.03
SPAWNING RUN									
17A	3	——	1.02	52.74	37.17	6.06	3.01	——	——
17B	5	——	1.23	63.55	28.14	6.26	0.82	——	——
18	1	——	2.00	73.00	20.00	4.00	1.00	——	——
All	9	——	1.24	61.00	30.25	5.95	1.57	——	——

Table IV.—Average Sex Ratio (Females/Males) and Stage of Development for Samples from Winter and Spawning Runs to the West Coast of Vancouver Island during the 1952–53 Season.

WINTER RUNS

Area	Sex Ratio	Percentage		
		Immature	Mature Unspent	Mature Spent
23	1.07	5.08	94.92	——
24	0.97	4.00	96.00	——
25	1.34	26.08	73.92	——
26	0.99	2.33	97.67	——
All	1.11	10.67	89.33	——
SPAWNING RUNS				
23	1.46	3.93	78.57	17.50
24	0.90	3.00	87.75	9.25
25	0.68	0.37	89.63	10.00
26	0.79	2.25	79.25	18.50
27	0.48	2.50	97.50	——
All	0.99	2.62	83.75	13.62

Table V.—Average Sex Ratio (Females/Males) and Stage of Development for Samples from Winter and Spawning Runs to the Lower East Coast of Vancouver Island during the 1952–53 Season.

WINTER RUNS

Area	Sex Ratio	Percentage		
		Immature	Mature Unspent	Mature Spent
17A	0.89	2.09	97.91	____
17B	0.74	2.81	97.19	____
18	0.70	0.92	99.08	____
All	0.84	2.14	97.86	____

SPAWNING RUNS

17A	1.21	____	92.33	7.67
17B	0.53	0.40	46.40	53.20
18	0.75	____	34.00	66.00
All	0.72	0.22	60.33	39.44

Table VI.—Average Length (Millimetres) and Average Weight (Grams) for Each Age in Samples from Winter Runs to the West Coast of Vancouver Island in 1952–53, with Numbers of Fish on Which Averages Are Based in Parentheses.

AVERAGE LENGTH

In Year of Age	Area 23	Area 24	Area 25A	Area 25B	Area 26	All Areas[1]
I	(2) 97.0	____	(1) 97.0	(3) 100.3	____	(5) 99.0
II	(193) 162.6	(54) 160.3	(295) 144.0	(24) 159.8	(19) 157.6	(290) 161.6
III	(1,402) 183.8	(145) 186.1	(3) 179.7	(671) 187.7	(225) 188.2	(2,443) 185.4
IV	(823) 198.0	(90) 196.6	____	(175) 199.5	(41) 198.3	(1,129) 198.1
V	(48) 209.4	(6) 209.8	(1) 205.0	(9) 209.6	(10) 205.1	(73) 208.8
VI	(14) 219.8	(1) 211.0	____	(4) 227.5	(2) 230.5	(21) 221.9
VII	____	(1) 212.0	____	(1) 233.0	____	(2) 222.5
VIII	____	____	____	____	____	____
?	(18) 188.2	(3) 184.7	____	(13) 193.7	(3) 174.0	(37) 188.7

AVERAGE WEIGHT

I	(2) 8.5	____	(1) 9.0	(3) 10.0	____	(5) 9.4
II	(193) 51.9	(54) 50.9	(295) 34.8	(24) 48.0	(19) 44.5	(290) 50.9
III	(1,402) 78.5	(145) 82.4	(3) 73.0	(671) 82.2	(225) 82.9	(2,443) 80.1
IV	(823) 100.2	(90) 98.9	____	(175) 100.7	(41) 98.3	(1,129) 100.1
V	(48) 121.5	(6) 119.0	(1) 124.0	(9) 121.8	(10) 107.4	(73) 119.4
VI	(14) 145.4	(1) 149.0	____	(4) 153.5	(2) 168.5	(21) 149.3
VII	____	(1) 123.0	____	(1) 168.0	____	(2) 145.5
VIII	____	____	____	____	____	____
?	(18) 86.7	(3) 79.7	____	(13) 90.5	(3) 69.0	(37) 86.0

[1] Samples from Area 25A not included in these averages.

Table VII.—Average Length (Millimetres) in Samples from Spawning Runs to the West Coast of Vancouver Island in 1953, with Numbers of Fish on Which Averages Are Based in Parentheses.

In Year of Age	Area 23	Area 24	Area 25A	Area 25B	Area 26	Area 27	All Areas
I	(2) 116.0						(2) 116.0
II	(179) 160.8	(147) 158.9	(31) 166.4	(3) 163.0	(3) 164.3	(3) 172.0	(366) 161.4
III	(671) 184.0	(171) 182.1	(169) 189.3	(178) 190.7	(258) 191.3	(116) 190.5	(1,563) 186.8
IV	(447) 198.6	(63) 199.7	(122) 204.2	(84) 204.3	(105) 202.8	(45) 205.1	(866) 200.9
V	(38) 211.7	(7) 211.3	(32) 218.8	(59) 217.3	(22) 216.4	(21) 218.0	(179) 215.9
VI	(10) 223.1	(8) 219.2	(28) 227.1	(60) 226.0	(6) 225.0	(9) 224.0	(121) 225.4
VII	(3) 230.0		(6) 238.2	(8) 234.1	(1) 242.0	(2) 220.0	(20) 233.7
VIII	(1) 239.0		(1) 249.0	(3) 242.3		(1) 244.0	(6) 243.2
IX			(1) 238.0				(1) 238.0
?	(49) 191.3	(4) 191.2	(10) 201.2	(5) 206.6	(5) 204.8	(3) 199.7	(76) 194.8

Table VIII.—Average Length (Millimetres) and Average Weight (Grams) for Each Age in Samples from Winter Runs to the Lower East Coast of Vancouver Island in 1952–53, with Numbers of Fish on Which Averages Are Based in Parentheses.

AVERAGE LENGTH

In Year of Age	Area 17A	Area 17B	Area 18	All Areas
I	(11) 105.4	(1) 119.0		(12) 106.5
II	(162) 156.6	(97) 154.7	(12) 157.2	(271) 155.9
III	(4,100) 184.7	(1,322) 181.3	(481) 183.3	(5,903) 183.8
IV	(2,493) 196.3	(486) 194.6	(234) 195.1	(3,213) 196.0
V	(245) 209.3	(45) 208.0	(28) 204.2	(318) 208.6
VI	(41) 213.9	(7) 218.0	(5) 214.0	(53) 214.4
VII	(5) 222.8			(5) 222.8
VIII	(3) 233.3			(3) 233.3
?	(36) 193.6	(2) 188.0	(3) 196.7	(41) 193.3

AVERAGE WEIGHT

I	(11) 12.3	(1) 19.0		(12) 12.8
II	(162) 44.6	(97) 44.8	(12) 49.6	(271) 44.9
III	(4,100) 77.2	(1,322) 73.5	(481) 82.0	(5,903) 76.8
IV	(2,493) 93.4	(486) 91.6	(234) 99.4	(3,213) 93.6
V	(245) 119.2	(45) 116.7	(28) 116.9	(318) 118.7
VI	(41) 135.5	(7) 137.6	(5) 130.8	(53) 135.3
VII	(5) 146.4			(5) 146.4
VIII	(3) 185.0			(3) 185.0
?	(36) 92.4	(2) 79.0	(3) 94.3	(41) 91.8

Table IX.—Average Length (Millimetres) in Samples from Spawning Runs to the Lower East Coast of Vancouver Island in 1953, with Numbers of Fish on Which Averages Are Based in Parentheses.

In Year of Age	Area 17A	Area 17B	Area 18	All Areas
I				
II	(3) 161.0	(6) 151.2	(2) 152.0	(11) 154.0
III	(155) 186.2	(309) 189.6	(73) 185.4	(537) 188.1
IV	(110) 199.0	(137) 206.5	(20) 198.8	(267) 202.8
V	(18) 208.9	(30) 217.9	(4) 220.0	(52) 215.0
VI	(9) 220.2	(4) 231.5	(1) 230.0	(14) 224.1
?	(5) 201.5	(14) 196.6		(19) 197.8

Table X.—West Coast Data on Catch and Spawning Deposition in Each of the Last Seven Years (See Text for Explanation of Corrections to Original Data)

Year	Catch (Converted to Grams; $\times 10^8$)	Average Weight of Fish in Catch (in Grams)	(*C*) Number of Fish in Catch ($\times 10^8$)	Recorded Extent of Spawnings (in Miles)	Average Intensity of Spawn Deposition	Extent of Spawning Corrected to Standard Intensity (in Miles)	(*S*) Estimated Extent of Spawning if All Spawning-grounds Had Been Surveyed (in Miles)
1946–47	535.2	98.7	5.42	32.4	3.1	33.5	39.4
1947–48	410.0	100.4	4.08	43.8	2.7	39.4	46.4
1948–49	499.0	102.7	4.86	41.1	3.2	43.8	51.5
1949–50	338.4	99.8	3.39	43.5	2.9	42.0	49.4
1950–51	228.6	100.6	2.27	54.9	2.9	53.1	62.5
1951–52	272.2	115.9	2.35	35.7	3.3	39.3	46.2
1952–53	0.2	84.7	0.002	64.3	3.2	68.6	80.7

Table XI.—Lower East Coast Data on Catch and Spawning Deposition in Each of the Last Seven Years (See Text for Explanation of Corrections to Original Data)

Year	Catch (Converted to Grams; $\times 10^8$)	Average Weight of Fish in Catch (in Grams)	(*C*) Number of Fish in Catch ($\times 10^8$)	Recorded Extent of Spawnings (in Miles)	Average Intensity of Spawn Deposition	Extent of Spawning Corrected to Standard Intensity (in Miles)	(*S*) Estimated Extent of Spawning if All Spawning-grounds Had Been Surveyed (in Miles)
1946–47	331.1	94.6	3.50	9.9	3.4	11.2	14.9
1947–48	362.0	105.1	3.44	17.4	2.6	15.1	20.1
1948–49	363.8	89.1	4.08	20.9	3.5	24.4	32.5
1949–50	365.6	98.0	3.73	15.1	3.7	18.6	24.8
1950–51	371.9	98.5	3.78	20.2	2.7	18.2	24.3
1951–52	372.4	99.1	3.76	31.5	2.9	30.4	40.5
1952–53	71.1	83.1	0.86	82.7	3.7	102.0	113.3

VICTORIA, B.C.
Printed by DON MCDIARMID, Printer to the Queen's Most Excellent Majesty.
1953

1,200-953-5363

Reprint from The Canadian Fish Culturist, No. 14, October, 1953, published by the Department of Fisheries of Canada, Ottawa.

Effects of Protective and Regulatory Legislation upon the Pacific Herring and Halibut Fisheries

by

W. E. Ricker

Editor of Publications, Fisheries Research Board of Canada, Nanaimo, B.C.

Regulatory and protective legislation respecting fish stocks is designed to benefit fishermen and the fishing industry. It tries to accomplish this by making fish more abundant, or easier to catch, or more valuable, than they would otherwise be. The fisheries for herring and halibut on the Pacific coast are of the type which attack a series of age-groups, rather than only fish which are about to mature and die. The problem of estimating the effects of regulation upon such fisheries has two aspects. Firstly, we may look at the yearly supply of recruits to a fishery, and try to make regulations so as to use them to best advantage. Alternatively, or additionally, we may cast about for means to increase this supply of recruits. Measures which accomplish one of these objectives may also assist the other, or they may work against it.

Aspect I. Best Use of Recruits

The optimum use of a given annual supply of recruits is the easier problem. Its solution evolved during the North Sea researches of the first decade of this century, and received its definitive form in Baranov's great work of 1918. What is needed is an estimate of the growth rate and the natural mortality rate in the fishery. If growth is less than natural mortality, it will be possible to obtain a larger gross catch by fishing harder. If growth exceeds natural mortality, fishing *less* will produce a greater yield. There are complications introduced by the fact that (relative) growth rate tends to decrease as fish grow older, and natural mortality too may change with age. Growth rate at a given age may also change as stock density increases or decreases in response to less or more fishing, or for other reasons; but this means only that computations of the equilibrium position must be repeated at frequent intervals. Then too, the smaller fish in the commercial stock tend to be harder to catch, and may bring a lower price per pound. This, together with the rapid growth of smaller fish, may suggest the wisdom of computing the effect of a minimum size limit or a mesh regulation instead of, or in addition to, a restricted level of exploitation. However, these are merely details, and the job of computing the equilibrium yield from different levels of fishing effort is fundamentally simple—as long as recruitment does not vary.

Aspect II. Maximum Recruitment

The problem of obtaining greater yield through maximum recruitment presents greater difficulties, though the general picture of what must occur seems clear enough. Removal of adult fish from a stock very generally promotes a greater percentage survival of eggs and larvae, in a variety of ways. At or near the maximum density of stock, a removal of adults may even increase the *absolute number* of annual recruits. The rather scanty information available on stock and recruitment in various fisheries suggests that this may be the usual situation.

This paper was read at a symposium on "The Effects of Protective and Regulatory Legislation upon Fisheries" held by the Canadian Committee on Freshwater Fisheries Research at Ottawa in January, 1953.

82157

Under the circumstances just described, the first effect of fishing an undisturbed stock is to increase the number of recruits which enter that stock each year. Later, with intensified fishing, spawning stock may become reduced so that the number of recruits begins to decrease, and it may even fall to below the primitive average level. In that event two stages of the influence of fishing upon recruitment can be distinguished:

Stage 1. In this stage a decrease of stock increases recruitment, while an increase of stock decreases recruitment. Population size is still regulated mainly by natural controls.

Stage 2. In this stage decrease of stock decreases recruitment, while an increase will increase it. Size of population tends to be controlled mainly by the fishery, which, left to itself, will fish it down to the point where it yields average economic returns, or sometimes even less.

Obviously the effect of protective legislation depends upon which Stage the fishery is in. In Stage 2 it is certain to increase recruitment, and this is true no matter whether it is adults or young that are protected. In Stage 1, however, while protection of young will increase recruitment, though only to a degree and temporarily, protection of adults will always *decrease* recruitment.

Thus an important task in fishery management is to ascertain the relation between adult stock and recruitment, so that the stage of exploitation can be identified. This task is made much more complex by the existence of year-to-year variation in success of reproduction associated with environmental variability. Random or short-term variation is not so bad, because its effects tend to average out over a period of a decade or two. Long-term or cyclical variation is much more difficult, because it is always possible that any observed trend in recruitment is the result of unknown environmental factors, rather than the current change in stock size.

Fishery Administration

Thus a fairly clear picture emerges of what a fishery administrator would like to be able to do. To make best use of stock on hand, he will need to know the rate of growth and the mortality rate, particularly the *natural* mortality rate, of the fish stock, and how they change from year to year. To promote optimum recruitment, he will want to know how recruitment has varied over the years in relation to prevailing levels of stock; and in particular, whether recruitment will be expected to increase or to decrease if the current level of commercial stock is decreased. The principal possibility of conflict in the results of protective legislation will occur in respect to a fishery which is in Stage 2 of exploitation *and* in which growth of the commercial stock is less than the natural mortality rate. In this situation decreasing the amount of fishing will decrease yield from the existing number of recruits, but it will increase recruitment a few years later; and vice versa. The two trends must be balanced one against the other.

In addition to the biological information above, an administrator will also need to know the relative vulnerability of fish of different sizes, and their relative desirability as shown by market price. He must then decide upon the economic objective at which he is aiming. The three psosibilities usually considered are: maximum total yield;

an adequate living for fishermen—that is, a certain minimum catch per unit effort; or a fishery in which the difference between cost of operation and sale price of the product is a maximum. The chosen goal and the anticipated reaction of the fish stock must then be fitted to the kinds of regulations which are available and are enforceable. In general, considerations of economics and public policy will play a large role in this final operation.

The discussion to follow will be restricted to the biological aspects of regulation of the two species assigned me, the herring and halibut of the Pacific.

Herring

The British Columbia herring fishery exploits a number of fairly discrete populations, these being demonstrable by average differences in vertebra number and by returns of tagged fish. The development of the fishery is described by Tester (1935) and more recent information is available from various sources (Tester, 1945, 1948; Stevenson *et al.*, 1951, and earlier papers of this series). The modern fleet of purse seiners, equipped with echo sounders, is an efficient means of capturing herring when they are concentrated prior to spawning time. Catches up to 300 tons per haul are not uncommon, and less than 50 tons per day constitutes poor fishing.

Regulation of this fishery has been of two types: closed seasons and catch quotas.

Closed seasons are set during the time of actual spawning. The reason is that herring are extremely vulnerable at this time, and inadequate spawning is feared if they are taken. In addition, the industry prefers to have fish taken prior to spawning, because oil yield is high early in autumn and decreases to zero at spawning.

Catch quotas were introduced at the time unlimited reduction of herring was first permitted, in 1937. The quotas chosen were set originally with an eye to past production of the Area in question. Quotas are quite often extended if fish still seem abundant when the limit is reached. On the west coast quotas have been removed since 1946-47, as an experimental measure for comparison with the east coast. However, the closed season remains.

Aspect I.

Natural mortality rate for recruited herring (age three and older) is estimated to be of the order of 50 per cent (Tester, 1948). On the other hand growth at age three is only about 25 per cent per year, and it decreases steadily at older ages (Tester, 1948, Fig. 6). Thus there is little question that better use of existing stock could be made by more intensive fishing than now occurs.

Aspect II.

To find a relation between *stock size* and *recruitment*, in herring, estimates of these two items are needed. Unfortunately neither is easy. Although tagging of herring is feasible and has yielded important information, the mortality involved has so far precluded any direct estimate of rate of exploitation, hence of stock size, in this way. Some idea can be obtained from a comparison of primitive and present survival rates, as shown by age composition of the stock; but this involves the assumption that it is fishing which caused the change, and anyway natural mortality may differ in the two

situations. Recently the size of post-fishing herring schools has been estimated by echo-sounding and compared with total stock (catch plus these schools), but this method is in its infancy. Up to now estimates of spawn produced have provided the only measure of stock size. The technique of spawning surveys has reached a considerable degree of refinement, and although it cannot be equated to number of adults with certainty, the figures obtained are of much use.

Relative size of individual year-classes is estimated by first computing the percentage of fish of each class present in the commercial stock each year. This is multiplied by an estimate of abundance—the catch per boat-day—and the sum of the occurrences of each year-class is taken (Tester, 1948).

For the west coast of Vancouver Island, a relation between the strength of each year-class and the amount of spawn which produced it is given by Tester (1948) as $r = -0.30$ for the spawning years 1931–43. This is not large enough to be statistically significant, and in later years it becomes numerically less. Using a more elaborate index of spawning for the years 1937-49, the correlation is -0.04 (Stevenson, MS). For the lower east coast of Vancouver Island, the 1937–49 relation is -0.18 (Stevenson), again a non-significant value. In this there is a complete absence of any indication that larger spawnings produce larger broods, and perhaps a suggestion that they tend to produce smaller broods. In terms of the analysis above, this suggests that these stocks have been near the boundary between Stage 1 and Stage 2 of exploitation, but probably closer to Stage 1.

Thus the indications available suggest that somewhat more intensive fishing of the herring stocks of age three and older would increase total long-term yield. The removal of quotas from the west-coast stock was of course designed to test exactly this proposition, and the experiment is being continued. It may soon become desirable to try the more drastic experiment of removing the closed season at spawning time, in order to ascertain the production of recruits by lower levels of stock than have been observed to date.

Halibut

From catch statistics, vessel log records, age studies, and tagging experiments, the scientists of the International Fisheries Commission in 1930–34 pieced together a picture of the history and present state of our two great Pacific halibut stocks, or groups of stocks, the "southern" and the "western". The latest published figures on catch and availability are given by Dunlop (1951) and by Bell *et al.* (1952). The southern stock consists of younger fish, has relatively fewer spawners, grows more rapidly, and has been more intensively exploited than the western one. The exact level of exploitation of these stocks at different times is subject to some uncertainty. The figures 40 per cent and 10 per cent are quoted for Area 2 and Area 3, respectively, in 1926 (Thompson and Bell, 1934). Results of recent tagging make it seem possible that the Area 3 figure was really somewhat higher than 10 per cent, and with the shortening of the fishing season in recent years the whole question of exploitation of different subdivisions of the stocks, and their contribution to the total catch, has become much more complex and uncertain.

Aspect I.

For the southern stock it was computed that, for any constant level of recruitment, reduced fishing would permit at least as great an equilibrium yield as was current in 1930, and possibly somewhat more. For the western stock it seemed that increase in equilibrium yield would come from more, not less, fishing (Thompson and Bell, 1934, p. 47).

Aspect II.

Direct evidence of the relation of stock size to recruitment was not available for either of the halibut stocks in the early 1930's. However, the level of abundance of the stock, and particularly of the mature stock, appeared to have fallen so far below its original magnitude that exploitation was assumed to have passed into Stage 2. An increase in recruitment was confidently expected from increased spawners in both stocks (Thompson and Bell, 1934).

The principal means of regulating the halibut fishery has been an annual quota imposed upon the total catch for each Area, beginning in 1932. Voluntary restriction had been in force a year or two earlier, and had been followed by increase in catch per unit of gear. The legal quotas were designed to continue this process. The benefits anticipated were: (1) that restriction would permit a greater accumulation of spawning stock, and hence, eventually, greater recruitment; (2) in the southern Area it would permit a somewhat better utilization of existing recruits, since the fish of this stock were thought to be growing somewhat faster than they decreased by natural mortality. The immediate effects upon the fishermen would be an increase in catch per unit effort, but a decrease in yearly catch and in total fishing done.

The adoption of this policy of quotas required considerable courage. The inevitable process of replacement of stock into the higher levels of the age structure meant that increase in availability from this cause would be slow at best. And this replacement would have to proceed far enough so that mature stock was substantially increased, before there could be much increase in spawning; after which there was to be another wait of 8 years or so before these larger broods appeared in the fishery in any considerable numbers.

The course of events has been somewhat different in the two stocks. In Area 3 the immediate increase in catch per unit effort, during the 1930's and early 1940's, was much greater than had been predicted on the basis of rebuilding the adult stock from constant recruitment; the difference has been computed by Burkenroad (1948, Fig. 5). Thus a phase of increasing recruitment must have been under way—an increase which began among broods produced by the small stocks of the late 1920's. During the later 1940's however, catch per unit effort in the western stock fell off to the level of the late 1930's, presumably because of decrease in recruitment from the denser stocks of 1936 and onward, but aided by a gradual increase in the catch quota. Recently catch per unit effort has started rising again.

In Area 2, the increase in catch per unit effort up to 1937 appears to have been about what would be expected on the basis of steady recruitment and stable growth rate. By 1947, availability had risen somewhat above the point that could have been supported by the old level of recruitment, suggesting that an increase in recruits had

occurred. In recent reports of the Commission, however, there are statements that the broods of 1943–45 on the Goose Island banks were much less numerous than those of 1939–42, and apparently this may be expected to reduce availability in the next few years.

As far as an outsider can judge, no interpretation of these various indications can yet be made with assurance. It might be argued that Area 3 has always been in Stage 1 of exploitation, since the low stocks of 1925–35 apparently produced more recruits than the increased stocks of 1936–43. But these differences might equally be "accidental", independent of stock density as far as present knowledge goes. In Area 2 increased stock was followed by some increase in recruitment, but it is now feared that a recession is in prospect, on some banks at least. Until there are better clues concerning the nature of these changes, the best policy may be to ignore them and base regulations upon the best utilization of whatever recruits come along, however unsatisfactory this may seem. Perhaps eventually the level of effort in one or other Area should be altered on a frankly experimental basis, but the procedure so far has in fact been an experiment that has provided some of the necessary information on the relation between stock size and recruitment.

One anticipated result of the quota regulation has been amply achieved—that of making fishing more successful. In part this results from increased stock density and in part from the greater vulnerability of the larger fish, which are now relatively more numerous. Whether it will ever appear desirable, or feasible, to translate the implied potential economic return into actual profits or royalties, by restricting the number of boats fishing, is a question of serious concern to the public and international policy of the two countries.

Summary

The biological information which is desirable for making fishery regulations includes (1) the relative size of the growth rate and the natural mortality rate in the population fished; (2) the relation between stock size and recruitment. Information on (1) permits a choice of the best level of exploitation for recruits on hand; information on (2) permits the choice of the level of stock which will yield a maximum number of recruits. Abundance of stock and recruits produced are often (not necessarily always) inversely related when exploitation is light (Stage 1), but become directly related when exploitation becomes sufficiently heavy (Stage 2).

British Columbia herring are not fished heavily enough to make most use of recruits on hand, and there is as yet no indication that even the smallest level of stock observed has produced less than the maximum recruits possible for the environmental conditions prevailing. In the Pacific halibut stocks, growth and natural mortality are so nearly in balance that no important change in long-term yield (from any given number of recruits) results from change in fishing effort, over the range observed so far. The relation between halibut stock size and recruitment is still obscure, although the lowest observed level of the Western stock produced more recruits than a subsequent higher level. The most striking effect of regulation has been to increase stock density and make fishing more successful during the curtailed fishing season.

Acknowledgments

The articles shown in the reference list have provided the factual material quoted in this paper, since the author has done no field work with either herring or halibut. Mr. H. A. Dunlop of the International Fisheries Commission, and Mr. J. C. Stevenson of the Fisheries Research Board of Canada, have very kindly co-operated by discussing the more recent findings of their investigations.

Literature Cited

BARANOV, F. I. 1918. *On the question of the biological basis of fisheries.* Nauchnyi issledovatelskii iktiologicheskii Institut, Izvestiia 1(1), 81-128.

BELL, H. F., H. A. DUNLOP and N. L. FREEMAN. 1952. *Pacific coast halibut landings, 1888 to 1950, and catch according to area of origin.* Int. Fisheries Comm. (Seattle), Rep. No. 17, 47 pp.

BURKENROAD, M. 1948. *Fluctuation in abundance of Pacific halibut.* Bull. Bingham Oceanogr. Coll., 11(4), 81-129.

DUNLOP, H. A. 1951. *The effect of fishing upon the stocks of Pacific halibut.* Proc. United Nations Sci. Conf. on Conservation and Utilization of Resources, 7, 16-20.

STEVENSON, J. C., A. S. HOURSTON and J. A. LANIGAN. 1951. *Results of the west coast of Vancouver Island herring investigation, 1950-51.* Rep. British Columbia Dept. Fish for 1950, pp. 51-84.

TESTER, A. L. 1935. *The herring fishery of British Columbia, past and present.* Bull. Fish. Res. Bd Canada, No. 47, 47 pp.

1945. Catch statistics of the British Columbia herring industry to 1943-44. Ibid., No. 67, 47 pp.

1948. The efficacy of catch limitations regulating the British Columbia herring fishery. Trans. Royal Soc. Canada (V), Ser. 3, 42, 135-163.

THOMPSON, W. F., and F. H. BELL. 1934. *Biological statistics of the Pacific halibut fishery. (2) Effect of changes in intensity upon total yield and yield per unit of gear.* Int. Fisheries Comm. (Seattle), Rep. No. 8, 49 pp.

EDMOND CLOUTIER, C.M.G., O.A., D.S.P., Queen's Printer and Controller of Stationery, Ottawa, 1953.

rinted from COPEIA, November 27, No. 4, 238-239
ted in U.S.A.

ARCTIC OR POLAR COD, *BOREOGADUS IDA*, IN MIRAMICHI BAY, NEW BRUNSICK.—*Boreogadus saida* (Lepechin) is known be circumpolar, and is abundant in the Arctic as of Asia and North America where it is comnly found in Hudson Bay and about Greenland. owever, there are few records of its occurrence uth of Greenland along the east coast of America. Since it is small and not sought for food in the me way as trout and cod (*G. callarias*), it has no ubt often been overlooked or mistaken for the ung of its larger cousin during the years of fisher- investigations in the Gulf of St. Lawrence and out Newfoundland. Suitably cold Arctic water tends southward along Labrador, to Newfoundnd, into the Gulf of St. Lawrence and even to stern Nova Scotia, though in the more southerly gions this water occupies an intermediate depth th warmer water both above and below it in mmer. In winter, however, the upper layer bemes cold and, at least from the temperature standint, any Arctic species living in this cold tongue Arctic water could move inshore into shallow ter in all of these regions.

In 1909, Kendall (The Fishes of Labrador, Proc. rtland Soc. Nat. Hist., 2 (8): 207–43) reported o specimens of *B. saida* from Chateau Bay, Belle le Strait (Lat. 52° N., Long. 55° 52′ W.), but Vlakov has thrown doubt on this record because of e extremely low number of gillrakers (24 comred to 36–42 according to Vladykov). In any case is questionable record stood as the most southerly pture of this species on the Atlantic coast of rth America until Vladykov (1945, Naturaliste nadien, Quebec, 72 (1–2): 27–39) recorded it ng the north shore of the Gulf of St. Lawrence d in the St. Lawrence River.

In the trap-net fishery for smelt in the Miraichi estuary (Lat. 47° 10′ N., Long. 65° 05′ W., approximately) during late January and February, 1951, four specimens of Arctic cod (Table I) were obtained; these were caught in 1⅛-inch-mesh smelt nets set beneath ice up to 2½ feet in thickness and

TABLE I

MEASUREMENTS (IN CM.) AND OTHER DATA ON FOUR SPECIMENS OF *Boreogadus saida*

Character	1	2	3	4
Length:				
Total	21.6	21.3	25.0	19.3
Fork	20.8	20.3	23.7	...
Standard	19.6	19.1	22.5	...
Head	5.3	4.8	5.9	5.2
Snout	1.6	1.5	1.8	1.5
Barbel	.15	.10	.20	.20
Premaxillary	...	1.8	2.3	1.8
Pectoral	3.7	3.2	3.7	3.5
Caudal peduncle	...	2.5	2.4	2.3
Interorbital	1.3	1.1	1.4	1.2
Eye	1.1	1.1	1.2	1.1
Gillrakers (left side)	33 + 10	34 + 10	28 + 10	30 + 8
Fin rays:				
First dorsal	11	13	12	13
Second dorsal	13	13	14	16
Third dorsal	18	23	19	21
First anal	16	17	15	17
Second anal	21	21	19	19
Ventral	6	5	6	
Pectoral	17	18	17	16
Vertebrae*	..	54	55	54
Sex	♂†			

* Not including the urostyle.

† This specimen was in an advanced stage of sexual maturity, indicating it would spawn in the late winter or early spring, thus agreeing with Vladykov's findings

in water temperatures of −1.5°C. According to reports no doubt others were taken, but were considered to be "just a queer sort of young cod fish with a forked tail and lower jaw stuck out beyond the upper." These reports also indicate that these fish had never been seen before by the fishermen who took them. It appears, thus, that conditions during the 1950–51 winter were such as to bring these fish into Miramichi Bay and that usually such conditions do not obtain. The 1950–51 winter in this area was remarkable for its relatively mild weather.

In all of the specimens the lower jaw protrude and the peritoneum was heavily speckled wit black.

Our specimens were sent to the Royal Ontari Museum of Zoology, Toronto, where Dr. W. Scott, Curator, Division of Ichthyology and Her petology, verified them; specimens 1 and 2 are no in that institution. Specimens 3 and 4 are in the co lections of the Atlantic Biological Station, St. An drews, N. B.—R. A. McKenzie, *Atlantic Biologica Station, St. Andrews, New Brunswick.*

366

INTERNATIONAL COMMISSION

FOR THE

NORTHWEST ATLANTIC FISHERIES

REPRINT FROM

ANNUAL PROCEEDINGS

VOL. 3

for the year

1952-53

PART 4

nowledge of Divisions of Stocks of Cod, Haddock, Redfish and merican Plaice in Subareas 3 and 2 of the Northwest Atlantic Convention Area

BY WILFRED TEMPLEMAN

Issued from the Headquarters of the Commission
Halifax, N.S., Canada
1953

owledge of Divisions of Stocks of Cod, Haddock, Redfish and American

ice in Subareas 3 and 2 of the Northwest Atlantic Convention Area

By WILFRED TEMPLEMAN

COD

cod provides the most important fishery eas 2 and 3, considerably more import- the sum of all other fisheries both inshore ore. The international nature of the n this area is mostly due to the large of cod. Information on continuity or of the cod stocks in these subareas obtained from average vertebral num- wth rates, studies of sexual maturity, distribution of parasites such as the ntode *Porrocaecum* and the copepod *ra*, and also from tagging. In the account it will be necessary to discuss coast of Newfoundland part of Sub- lso since at the northern and southern is area there are cod migrations between nd 4. Subareas 2 and 3 and the west Newfoundland part of Subarea 4 have erred to in this paper as the Labra- foundland fishing area.

ebral Studies. Over twelve thousand columns from more than 130 different well scattered over the Labrador-New- d fishing area have been studied. The of vertebral numbers (not including the in the Newfoundland area are over 54 nd offshore along the east coast of New- d to the northern edge of the Grand Bank g the coast of Labrador. The vertebral drops to usually below 53 on the central hern part of the Grand Bank and on the half of the west coast of Newfoundland rmediate values elsewhere.

ebral averages of cod in the Labrador hore and offshore, the Newfoundland t inshore and offshore, and on the north- of the Grand Bank are not statistically so that the population could be the same. all see later, however, from other evidence e differences between various parts of k which show that while some mixing occurs it is very incomplete. Vertebral averages, on the other hand, show this northern stock to be distinct from that occupying the body of the Grand Bank generally and particularly from the cod stock on the southern part of the Grand Bank. It is most likely that the barrier between these two stocks is the layer of below zero water that surrounds at intermediate depths the western, northern and eastern edges of the Grand Bank.

Vertebral averages show a fairly distinct stock of cod along the southern half of the Newfoundland west coast. Gradually declining vertebral averages from the Strait of Belle Isle inward along the northern part of the Newfoundland west coast indicate an apparently seasonal extension of the east coast population into the northern part of the Gulf of St. Lawrence providing good fisheries in the Belle Isle Strait area. The cod stocks of the Labrador area, Subarea 2, are distinct from those of west Greenland, having considerably higher vertebral averages.

Growth Rates. The slow-growing Labrador cod show distinct differences in growth rate from the Newfoundland east coast cod which grow somewhat faster. The growth rate of the cod on the north and north-eastern part of the Grand Bank is still more rapid. The cod on the south and south-western part of the Grand Bank are by far the fastest growing in the whole Labrador-Newfoundland area. Thus from growth studies it is seen that the Labrador-Newfoundland east coast and northern edge of the Grand Bank cod which show no readily recognizable differences in vertebral averages are yet distinct enough to show considerably different growth rates. Hence the stocks cannot be very greatly intermingled.

Sexual Maturities. The size at first sexual maturity in the cod of the Labrador area appears to be small, that on the east coast of Newfoundland and on the northern and western

edges of the Grand Bank intermediate, and that on the southern part of the Grand Bank is by far the largest of all. Age of cod at first sexual maturity does not show such great differences as does size.

Incidence of the cod-nematode Porrocaecum in cod flesh. The incidence of the nematode parasite *Porrocaecum* has been studied in the fillets of over ten thousand cod. The parasite appears to have a long living period in the flesh and even the dead parasites can be recognized since the cuticle remains. Infection with this parasite is at its highest point, from 25 to 50 per cent of the fish infected, on the southern half of the west coast of Newfoundland and on the western half of the south coast. This population is shown to be somewhat distinct also by vertebral number and by tagging.

On the east coast of Newfoundland infection is low, usually 1 to 5 per cent of the fish. Infection of the Grand Bank is typically low mostly 1 to 3 per cent of the fish. On St. Pierre Bank infection on the northern part which is near a grey-seal colony is high—about 20 per cent, while on the southern part it is lower, about 4 per cent infection. Thus even on an area as small as St. Pierre Bank the northern and southern populations of cod apparently show considerable distinctness. The cod of the southern part of St. Pierre Bank with about 4 per cent infection show considerable distinctness from those of the neighbouring Banquereau with over 20 per cent infection.

Incidence of the cod copepod parasite Lernaeocera. The incidence of this parasite has also been studied in over ten thousand cod well distributed over the Newfoundland-Labrador area.

High infestation with *Lernaeocera* is characteristic of the inshore areas. The life of the parasite appears to be moderately long and even after the parasite has disappeared, the head with the neck stalk protruding can be found at the apex of the gills. It is a parasite very suitable for studies of the relationship of inshore and offshore cod populations. Infestation is low in Labrador mostly 0 to 3 per cent of the fish and moderately high in the coastal areas of Newfoundland ranging from 1 to 28 per cent and averaging bet and 10 per cent of the fish infected. T tral, north-east, east, south and south-we of the Grand Bank have a very low infe on the average considerably less than 0.5 p and usually zero infection in a sample of hundred fish. On the northwestern edge Grand Bank, however, infection is high samples showing over 5 per cent of the cod i with *Lernaeocera.* This is in agreemen rates of infection several times as high in th bouring coastal cod of the Avalon Penins indicates relationship between the coastal of the extreme south-east Newfoundlan and those of the western edge of the Gran This relationship has been shown also captures of tagged fish.

Tagging. About sixteen thousand c been tagged in the Labrador-Newfoundland eight thousand since 1947. The per returns from the inshore tagging are, w best varieties of tags, thirty per cent or while returns from tagging on the Gran are usually considerably less than five p

Tag returns have shown considerab vidual movement along the east coast o foundland and some movement southwar Labrador to the east coast. In a great this area there is deep warmer Atlantic close to the coast and the fish can app move considerably in this layer over Tagging returns also show considerable and winter movement of cod from the s part of the east coast to the western and western edge of the Grand Bank for sp followed by an onshore movement of th with the capelin in June. In the same w the vertebral numbers show a barrier at the northern edge of the Grand Bank high vertebral count northern and low v count southern cod stocks so it is that c inshore tagging on the southern part of coast of Newfoundland are often return the northern and north-western edges bank but no recaptures are obtained south-eastern part of the bank. Similar tagging on the north-western edge of th Bank there is a high percentage of re inshore along the Avalon Peninsula and

ile from tagging on the southern part rand Bank there are few inshore recap- ne along the east coast, and a few along a coast of the island.

ging at Bay of Islands on the west coast undland has shown a stock of cod which southward out of the Gulf in the early the Rose Blanche Bank area, not beyond Bank and Hermitage, providing a good shery on the western part of the south Newfoundland, a return migration to the half of the west coast taking place late spring. Tag returns also indicate ent of east coast cod into the Gulf of rence through the Strait of Belle Isle. by the fishery this movement is inward nd out in the autumn.

ging on St. Pierre Bank has shown a idespread movement of fish from this stly to the south coast of Newfoundland, the Grand Bank and two across the an Channel to Banquereau. Apart from ed on St. Pierre Bank it is very unusual ish tagged in Newfoundland to cross the an Channel to the Nova Scotia banks e southern side of the Gulf of St. Law-

HADDOCK

he Newfoundland area haddock are found dance only on the southern part of the Bank and on St. Pierre Bank. There is astward movement of the mature and mature fish during the summer time. another small population on the western he south coast and on the southern part west coast of Newfoundland. A few apparently of still a fourth stock occur Flemish Cap. Studies of growth, year- ndance and vertebral number have been ade and tagging experiments have been ut.

tebral Numbers. Vertebral studies own no distinction between Grand Bank Pierre Bank haddock. The haddock of h-western angle of the coast of Newfound- the basis of several samples only, have l numbers lower than those of the two bank stocks and hence may be distinct from them. This stock is, however, of little importance. The possession of lower vertebral numbers by the Newfoundland haddock stocks show that they are distinct from the Banquereau stocks across the Laurentian Channel.

Tagging. Tagging of about a thousand otter-trawl-caught haddock on the Grand Bank has given no returns. A small amount of inshore tagging near Burin of trap-caught haddock gave several recaptures, one from St. Pierre Bank.

Growth Rates and Year-Classes. Growth rate studies and the maintenance over a considerable number of years of year-class differences show that the Grand Bank and the St. Pierre Bank haddock are relatively distinct. There appears to be some intermingling south of Green Bank and the few very large haddock caught on the Grand Bank where growth is slow appear to be of the St. Pierre Bank type. On the Grand Bank itself there is apparently considerable intermingling of stocks and no considerable differences exist between the stocks on the different parts of the bank.

A very small stock of haddock with a distinctly different growth rate pattern exists on the Flemish Cap.

REDFISH

(*Sebastes marinus*)

Evidence for distribution of stocks of redfish has mainly come from two sources, vertebral numbers and distribution of the redfish copepod parasite *Sphyrion lumpi*. Over eight thousand vertebral columns have been studied from Cape Chidley to George's Bank.

Vertebral Numbers. The northern stocks from Labrador-Newfoundland and from the Gulf of St. Lawrence generally have vertebral counts higher than those of the Nova Scotian shelf area and the vertebral number is slightly lower still in the Gulf of Maine. Even in the northern areas, however, redfish with very low vertebral averages will often be found quite near redfish populations with very high vertebral averages indicating either very little movement of redfish or considerable differences between vertebral numbers in different year-classes.

Distribution of Sphyrion lumpi. For many years it has been known that a heavy infection of redfish with the copepod parasite *Sphyrion lumpi* existed in the Gulf of Maine. Another centre of heavy infection by the parasite has been found in the redfish populations of Labrador while a minor centre exists on the eastern edge of the Grand Bank. Very low infestation by *Sphyrion* is found on the western part of the Grand Bank and in the Gulf of St. Lawrence and the parasite is apparently absent in the eastern Nova Scotia area. The external body of the individual *Sphyrion* parasite while certainly lost in time, would appear to have an existence long enough for it to act as a tag. Also the head remains embedded for a long time or indefinitely after the death of the parasite and by candling the fillets a very useful check on *Sphyrion* infestation can be obtained. The fact that high infestation can exist in populations of redfish while within a very short distance other populations show very low or no infestation is an indication that redfish do not migrate freely over large areas.

Age and Growth and Maturity Differences. These are being studied. There are differences in various areas in sizes at maturity and growth differences undoubtedly exist but age reading of redfish otoliths is not yet on a completely firm foundation.

AMERICAN PLAICE

(*Hippoglossoides platessoides*)

Vertebral and fin-ray averages from large numbers of American plaice have shown no statistical differences within areas 2 and 3. Maturity and size differences exist which allow some differentiation of stocks. The American plaice of the large population commercially fished on the eastern side of the Grand Bank mature at a considerably larger size and grow much larger than inshore plaice. Age studies have been begun but because of the small otoliths and the great age (20-40 years) of commercial plaice accurate and reproducible age readings are difficult to obtain.

SUMMARY

Cod. Three well marked divisions of the cod stock in the Labrador-Newfoundland area have been shown by vertebral counts and t returns—the Newfoundland southern west and western south coast stock, the Lab east coast Newfoundland and northern Grand Bank stock, and the southern and Grand Bank stock. These three stock latter two of major importance, are well sep by migratory and vertebral patterns, and r ion between them is hindered by natural b apparently mainly bottom temperature ba Growth rate studies show enough distin within these stocks to indicate that co intermingling within a stock does not occu is well illustrated in the considerable differences between the Labrador, Newfou east coast and northern Grand Bank secti the northern stock. Within a stock, ho the lack of intermingling is due more tance than to a temperature or depth ba

Tagging and *Porrocaecum* and *Lern* infestation show the relation of the cod western edge of the Grand Bank and th the southern part of the east coast of New land and the lack of relation of cod in th to the southern Grand Bank cod popul The inter-relationships of the St. Pierre south coast, and southern Grand Bank ar complex. Some intermingling is show further study is needed. There is consid intermigration between St. Pierre Bank a south coast cod stocks. The deep warm of the Laurentian Channel is to a consid degree a barrier to southward movement Newfoundland stocks of cod. In the no cod stocks of the Labrador area, Suba are shown by highly different vertebral av and lack of any considerable intermigrat tagged fish to be distinct from those o Greenland.

Haddock. There are two large ha stocks, the Grand Bank and the St. Pierre stocks, with a minor stock at the southw corner of the island and very minor stock Flemish Cap. The Newfoundland haddock lations are separated from those of the Scotian Banks judging by average ve numbers, and the St. Pierre Bank and the Bank stocks are shown to be relatively d by differing growth rates and differences in

ndance continuing for a considerable
f years following occasional differences
lass survival.

fish. Vertebral numbers decrease gra-
om north to south and the discontinu-
ibution of the redfish parasite *Sphyrion*
th populations of high infection close to
h low infection indicates lack of large-scale long-distance migration in this species.

American Plaice. The stock fished commercially on the eastern edge of the Grand Bank can be distinguished from the inshore stocks by larger size at sexual maturity and larger final size. Average vertebral numbers and fin-ray counts do not show distinct differences in plaice populations within Subareas 2 and 3.

367

NTERNATIONAL COMMISSION

FOR THE

NORTHWEST ATLANTIC FISHERIES

REPRINT FROM

ANNUAL PROCEEDINGS

VOL. 3

for the year

1952-53

PART 4

Identification of Major Groundfish Stocks in Subarea 4 of the Northwest Atlantic Convention Area

BY W. R. MARTIN

Issued from the Headquarters of the Commission

Halifax, N.S., Canada

1953

PART 4

Scientific Papers Specially Prepared for the Annual Meeting

May, 1953

ification of Major Groundfish Stoc ks in Subarea 4 of the Northwest Atlantic Convention Area

By W. R. MARTIN

servation of the groundfish fishery of the st Atlantic ocean is the primary purpose nternational Commission for the North- antic Fisheries. Intelligent management rge fishery will be based firstly on know- the definition of the various groundfish their distribution and movements, and on an understanding of the factors which ie the size of the catch which may be om these stocks. It is of particular to determine whether or not regulation g may be expected to increase the long- ld of any particular groundfish stock.

development of a mesh regulation for fishing in Subarea 5 has been based ition of the haddock stock and an assess- the effect of fishing on its yield to the Similar information must be collected major cod, haddock, redfish and halibut roughout the Convention Area.

s the purpose of this report to review, in y form, the status of our knowledge of cipal groundfish stocks in Subarea 4 as a considering conservation requirements. investigations of the population dynamics arious groundfish stocks will provide the determining optimum fishing conditions relation of present fishing practices to an e of "best use" of our groundfish resources. sic information as natural and fishing ies is not well understood but definition dfish stocks in Subarea 4 has been studied 25 years and the results of investigations more important species (cod, haddock, nd halibut) may be described.

Cod

Cod is the most important groundfish species in Subarea 4 with landings normally exceeding 200 million pounds (100,000 metric tons). The greatest part of the catch is landed in Canada and more than half of these landings are taken by inshore, small-boat fishermen. The cod is a cold-water species and its relative importance increases from south to north in Subarea 4. Only about a quarter of the groundfish landings are cod at the mouth of the Bay of Fundy but cod make up more than 90% of the groundfish landed along the Gaspé coast and the north shore of the Gulf of St. Lawrence.

The deep-water Fundian Channel between Georges and Browns Banks and the still deeper Laurentian Channel between St. Pierre Bank and Banquereau are barriers to the movement of cod. Except for occasional movements of individual cod across these channels we may consider that the cod populations along the Nova Scotian Coast, in the Western Gulf of St. Lawrence, and on the Nova Scotian offshore banks are resident in Subarea 4. The evidence is based on about 2,500 returns from some 22,000 cod tagged in Subarea 4 and on vertebral counts on about 28,000 cod sampled throughout this "Maritime" fishing area. More recent observations on growth, year-class strength and infection with parasites support the results of pre-war tagging and vertebral-count investigations.

Within Subarea 4 we find a great many cod populations which may be divided into a number of major stocks:

(1) **Western Nova Scotia**—Resident populations show restricted movement and do not

mix with eastern or offshore cod. The number of vertebrae is low, about 10% are infected with cod-worms, growth rate is very rapid, total mortality is high with very few cod living more than seven years, and spawning is in April and May.

(2) **Central Nova Scotia**—Resident populations show very restricted movement. The majority are spring spawners with a vertebral count which is higher than that of western Nova Scotia but lower than that to the east and offshore. A population of fall-spawning cod with a low vertebral count is also found in the Halifax area.

(3) **Eastern Nova Scotia**— Populations show a movement offshore in winter and inshore in summer. Vertebral number is high and about 20% are infected with cod-worms. Growth rate is slower than that of western Nova Scotia cod and mortality is lower. Cod are not fully recruited to the fishery until they are about five years old and they are of little importance to the fishery beyond an age of 11 years.

(4) **Western Cape Breton**—The cod population along the western Cape Breton coast moves out of the Gulf of St. Lawrence in the autumn, winters just north of the offshore banks and returns around Cape North to the Chéticamp area again in the spring. Spawning has been observed in June and July.

(5) **Offshore Nova Scotia**—Both resident and migratory populations of cod are found on Nova Scotian offshore banks. Some appear to be resident on the banks all year round, others move in along the eastern Nova Scotian shore in summer months and still others move into Cape Breton and the Gulf of St. Lawrence as far as Gaspé for the summer. The cod on eastern banks show a greater tendency to migrate Gulfwards than those on the western banks. Western banks fish spawn in early spring and eastern banks fish in late spring. Vertebral number is high and cod-worm incidence low in offshore cod. Growth is slower than that of western Nova Scotia but faster than that of Gulf cod. Most fish are contributed to the fishery at from five to twelve years of age. Offshore catches increase during winter months with concentration of fish in deeper water and offshore mov of cod from inshore waters and the Gulf.

(6) **Southern Gulf of St. Lawre** Populations in the Prince Edward Islan restrict their movements to the southern of St. Lawrence. Tag returns outside th are few, vertebral count is low and in with cod-worms high. Growth is slow a contribute to the fishery for several years four to fourteen). Spawning is somewha in the Gulf (July-August) than on Nova grounds.

(7) **Gaspe**—Cod are abundant in th pé area of the Gulf. Vertebral counts are than those of the southern Gulf and to those of Cape Breton and Nova Scotia o banks. Worm incidence is high with 50% of the cod infected with the cod- Growth rate is slow and fish as old as 15 are common in the catches. The averag of cod in Gaspé landings is about eight Spawning occurs in late summer (August-Se ber).

(8) **Eastern Gulf of St. Lawre** Cod populations on the Newfoundland s the Gulf are quite distinct from those west of the Laurentian Channel. Tagging a migration out of the Gulf in winter and a movement to the Gulf in spring. Ver counts are lower than those observed at Breton. Large, old, slow-growing cod are from this eastern Gulf area.

(9) **Northern Gulf of St. Lawre** Slow-growing cod are found in the no Gulf. They do not mix with those taken of the Laurentian Channel.

To sum up, we find a great many p tions of cod in Subarea 4. In general, major stock of cod remains distinct. Tho central and western Nova Scotia move rela little. Those in the Gaspé and Prince E Island areas move greater distances but r year-round in the Gulf. Cape Breton cod a seasonal movement offshore in the autum Gulfwards in the spring. Resident offsho populations are augmented by migratin during late autumn and winter months. migrating cod move inshore and into the

ıe Laurentian Channel during summer
The populations along the Newfound-
re and Quebec north shore of the Gulf of
rence are distinct from those taken west
ıurentian Channel.

Haddock

ldock landings from Subarea 4 are smaller
ose from Subarea 5 but the relative
ce of haddock varies widely. Landings
a peak of 130 million pounds (60,000
ons) in 1930 and fell below 40 million
(18,000 metric tons) in 1942. Canada
ited States fishermen share the catch
qually. Haddock are normally found
er water than cod and at more southerly
. They are abundant all along the
otian coast in both inshore and offshore
ut landings from the Prince Edward
New Brunswick, Quebec and Newfound-
as of the Gulf of St. Lawrence are very

dock are more restricted to bottom than
for this reason Subarea 4 haddock are
re sharply separated from those in Sub-
and 5 than noted above for cod. Sub-
addock have a low vertebral count, a
wth rate and a high mortality rate, with
g beyond an age of seven years. Sub-
addock also have a low vertebral count
th rate is low and older fish are caught.
strength of year-classes varies widely
ck and it is of interest to note that the
t year-classes differ in these three sub-
n recent years the landings have shown
wing outstanding year-classes: 1942 in
3, 1943 in Subarea 4 and 1948 in Sub-
The evidence based on some 25,000
counts, 14,000 tagged haddock and an
postwar program of sampling for sizes
of the commercial catch demonstrates
at Subarea 4 haddock are distinct from
lock of adjacent subareas except for
xing with Subarea 5 haddock in the
undy area.

stigations of the haddock in Subarea 4
wn a number of major haddock stocks:

(1) **Northern Bay of Fundy**—Haddock appear during summer months in this region. Their growth is rapid and tagging has demonstrated that they are related to the New England stock.

(2) **Southern Bay of Fundy**—The population off western Nova Scotia moves into the Bay of Fundy during summer months and away from the Bay in winter. Growth is slower than that of northern Bay of Fundy haddock. During the past few years the 1939, 1943 and 1945 year-classes have contributed a major part of the landings.

(3) **Browns Bank**—The slowest-growing haddock of Subarea 4 are resident on Browns Bank. This population differs sharply from that of Georges Bank to the west and LaHave Bank to the east.

(4) **Southwestern Nova Scotia**—The haddock of this area are faster-growing than those of Browns but slower-growing than haddock taken from offshore and eastern Nova Scotia grounds. Tagging results show an eastward drift of large haddock from the area but most tag returns were taken from the area of tagging, indicating a resident stock. The 1943 year-class dominated landings from 1947 through 1951. Western Nova Scotia haddock are heavier at any given length than those taken to the east.

(5) **Eastern Nova Scotia**—A population of fast growing young haddock in this area shows seasonal offshore movement. Vertebral count is higher than that of western Nova Scotia. The 1943 year-class in particular and lately the 1947 brood have dominated landings during recent years.

(6) **Cape Breton**—The haddock of the southern Gulf of St. Lawrence are large, fast-growing fish which move out of the Gulf in the late autumn to return again in late spring. They winter on Nova Scotian offshore banks. These haddock move into the Gulf close to shore around Cape Breton with the oldest haddock moving first. These migratory haddock grow quickly (although more slowly than those of Subarea 5) and they have the highest vertebral counts in the whole area.

(7) **Offshore Nova Scotia**—Resident populations of haddock with rapid growth and high vertebral counts are found offshore. During winter months these fish are joined by haddock from inshore Nova Scotia and the southern Gulf of St. Lawrence; the vertebral count appears to be somewhat higher at this season. The 1943, 1944, 1946 and 1947 year-classes have all contributed significantly to the landings from offshore banks during recent years.

There are, then, many populations of haddock in Subarea 4. The haddock populations off western Nova Scotia differ from those found offshore and around eastern Nova Scotia by migrating less extensively, by growing more slowly, by weighing more for a given length, by showing differences in the relative importance of year-classes and by having a lower vertebral count. The haddock populations of eastern Nova Scotia migrate seasonally, apparently to avoid the particularly low water temperatures which appear in this area during winter months.

Redfish

Redfish landings from Subarea 4 were small before 1945 but annual catches as high as 170 million pounds (77,000 metric tons) have been taken during recent years by United States trawlers. The Canadian catch is negligible.

The redfish of Subarea 4 differ from those of adjacent subareas in growth, meristic counts and parasitization. The absence of the external parasite *Sphyrion lumpi* is a striking characteristic of Subarea 4 redfish.

Within Subarea 4 there are many isolated deep water populations differing one from the other. Heavily exploited populations of small redfish are found off western Nova Scotia, central Nova Scotia and Cape Breton. Populations of large redfish have been found in deep water along the outer edge of Nova Scotian offshore banks and along the Laurentian Channel as far as Gaspé. Redfish appear to concentrate in tongues of deep water between the banks.

There are many gaps in our knowledge of redfish populations in Subarea 4—their size and extent, their diurnal and seasonal movements and their life history. The validity of ag ing is not well established and population mics are therefore not understood. I investigations of these problems are r before it will be possible to describe Sub redfish stocks in greater detail.

Halibut

Annual halibut landings from Sub average about four million pounds (2,000 tons) and most of the catch is taken in dee off Nova Scotia. Catches are made c shore off southwestern Nova Scotia and A but more are taken along the outer edge shore banks. Most of the Subarea 4 catch is landed in Canada. The halibut tions of Subarea 4 do not cross the Fundi Laurentian Channels; they are distinc the halibut of other subareas.

Within Subarea 4 investigations have a number of halibut populations, none o move very extensively. There are seasona ments, apparently related to changes in temperature; halibut move inshore coi with the warming of bottom waters.

The halibut found off southwestern Scotia differ from those of the norther of St. Lawrence in colouration, in size-a composition and in growth. They have or cherry-tinged, rather than grey, bellie are smaller and younger fish, and they gro rapidly. Tagging has shown that even this area the Roseway-LaHave halibut intermingle with those found to the west man Bank halibut move east to the Cap Island area in late summer and return deep water in winter where they spawn. is a drift of some halibut to eastern grou no movement to the west.

The halibut of the Anticosti region Gulf of St. Lawrence are old, slow-growing Tagging has shown very limited movemen the Laurentian Channel with none re-c west of this Channel.

Summary

(1) All four of the important gro species of Subarea 4 (cod, haddock, redfi

re, for management purposes, distinct tocks of adjacent subareas.

Within each species we find a number stocks in Subarea 4.

Groundfish are taken both outside and three-mile territorial limit and in each find that some populations are fished hore and inshore as they migrate from to another. Halibut move inshore at ble Island; cod and haddock move t Cape Breton in spring and autumn months; and redfish may be taken close to shore off Digby Neck, Cape Breton and Gaspé.

(4) Bottom-living haddock and halibut stocks are more sharply divided by deep water channels than the more pelagic cod and redfish.

(5) Haddock and halibut are sensitive to very cold water. They move into shoal water during summer months and leave again before winter. They show more clearly defined migrations than the colder-water cod.

368

NTERNATIONAL COMMISSION

FOR THE

NORTHWEST ATLANTIC FISHERIES

REPRINT FROM

ANNUAL PROCEEDINGS

VOL. 3

for the year

1952-53

PART 5

ng Term Changes in Hydrographic Conditions and Corresponding Changes in the Abundance of Marine Animals

BY WILFRED TEMPLEMAN, AND A. M. FLEMING

Issued from the Headquarters of the Commission

Halifax, N.S., Canada

1953

Term Changes in Hydrographic Conditions and Corresponding Changes in the Abundance of Marine Animals

BY WILFRED TEMPLEMAN AND A. M. FLEMING
NEWFOUNDLAND FISHERIES RESEARCH STATION

INTRODUCTION

e following account of marine animal ıce and climatic variations has parti- ference to Subareas 3 and 2 of ICNAF.

are grateful to the Meteorological Station 'orbay Airport for the use of air tempera- :a. Thanks are also due to Mr. Hubert of the staff of the Newfoundland Station use of his squid abundance data and to P. Hunt for assistance in a survey of aphic data for Subareas 3 and 2 in an to find valid comparisons.

:A AND AIR TEMPERATURES

ter Temperatures Subareas 3 and 2.

Subareas 3 and 2 there are no seawater tures for long periods and in the same s. The hydrographic records of the ıdland Fisheries Research Station date m 1947 but since that date six sections ıe Labrador current from southern Labra- ıe southern extremity of the Grand Bank en taken regularly at approximately the ne of the year, the southern ones twice n March—April and July—August and hern in July—August only. Two sect- hward as far as Cape Chidley are occu- ore irregularly. The former Fisheries ı Station under Dr. Thompson at Bay ewfoundland, obtained temperature re- tween 1931 and 1935 but not at the same year nor from the same stations as the ent records.

International Ice Patrol has a series ls for the same sections on the eastern he Grand Bank for 8 years from 1934 to d from 1948 to the present. Further section across the Labrador Sea from South Wolf Island, Labrador, in Subarea 2 to Cape Farewell, Greenland, Subarea 1, has been occupied once during each of 15 summers between 1928 and 1952. Within this group of observations the longest unbroken stretch is the series of 5 years from 1948-52. The Ice Patrol has taken many other sections across the Labrador current in addition to the above but none were repeated for so many years.

In addition there are hydrographical observations in Subarea 3 by French research ships in occasional years, particularly since 1924. In recent years the Atlantic Oceanographic group at St. Andrews has made some summer and autumn cruises in Subarea 3. Canadian hydrographic ships have taken temperatures particularly in Subarea 2 and innumerable bathythermograph observations have been taken by U.S. and Canadian naval and other ships especially in Subarea 3.

Iselin in the schooner Chance carried out hydrographic observations in July—August, 1926, taking sections across the Labrador current in Subareas 2 and 3. During the Canadian Fisheries Expedition of 1914-15 under the direction of Dr. Hjort, hydrographic stations were occupied in 1915 in the southwestern part of Subarea 3 on St. Pierre Bank, Green Bank and in neighbouring channels. In 1913 the Scotia expedition under Dr. D. J. Matthews carried out the first systematic hydrographic study of the Grand Bank and Subarea 3 waters and in Subarea 2 at the level of Hamilton Inlet made a section across the Labrador current. In the summer of 1910 the "Michael Sars" Expedition made two sections of the Grand Bank area, one east to west over the northern part of the bank and one from St. John's southward across the bank. A more detailed review of these and other hydrographic observations in Subareas 2 and 3 is to be found in Smith, Soule and Mosby (1937) and Dunbar (1951).

There are many difficulties in making use of these data for a study of long-term changes in hydrographic conditions. It is noticeable at once that apart from very recent data there is too little agreement in the position of the stations from year to year for ready comparison to be made. Also, comparisons from isolated years are not of great importance in assessing long-term trends since temperatures in individual years may vary greatly during any period. Thus in the recent presumably warmer period, in Subareas 2 and 3 the year 1950 was characterised by a greater abundance of very low temperature water than any other year since 1928 for which good records exist.

From the hydrographic records of the Canadian Fisheries Expedition in the neighbourhood of St. Pierre and Green Banks in 1915 (Bjerkan, 1919) it is indicated that bottom temperatures on the average were lower in 1915 than in 1946-49 and in 1951-53.

Mr. Floyd Soule, Oceanographer with the Ice Patrol, in a private communication says that the part of the eastern branch of the Labrador current measured on the east side of the Grand Bank has been decidedly less since the war than it was during the period 1934-41.

It is indicated by our examination of the available data, in so far as former stations were near present stations, that no long-term temperature data suitable for comparison exist and in general only the recent data are suitable for any rigid comparing of sea temperatures from year to year.

St. Andrews Surface Temperatures.

Probably the best series of sea temperatures near enough to Subarea 3 for a possible temperature relation is the daily series of surface temperatures taken at St. Andrews, N.B. since 1921. (Hachey and McLellan, 1948). The combination of extremely high tides and narrow entrances to Passamaquoddy Bay forms an effective water mixing mechanism, consequently the surface temperatures at St. Andrews are fairly representative of the general temperatures of the ocean water in the area. The annual mean surface temperatures at St Andrews shown in Figures 1 to 4 were above or equal to the 1921-1947 a during the years 1927-33, 1936-38, 1944-4 1949-52. Judging by information fro Arctic, most of the years since 1922 ma been in a warmer period. The series is, the not really extensive enough to trace lon changes but it is useful as showing a trend higher temperatures in recent years and for ing any effect of higher and lower tempe short-term periods.

Since there is nothing comparable in Su 2 and 3 and since there is a good possibilit the St. Andrews temperatures reflect in degree Subarea 3 temperatures, the St. An temperatures will be used for comparison.

St. John's Air Temperatures.

From the Dominion Meteorological S at Torbay Airport a series of mean mo air temperatures has been obtained for St. J Nfld. from 1872, with some breaks, until There is also a similar series for Torbay Ai 5 miles from St. John's, from 1942 to From these the mean yearly temperature been calculated. For 46 months when r were taken from both St. John's and T Stations in 1944-45 and 1948-51, the T temperatures have been adjusted to rep St. John's temperatures and these adjusted peratures have been used for 1942-52. (I overlapping period Torbay temperatures w the average 0.6°C. lower than St. John's tem tures).

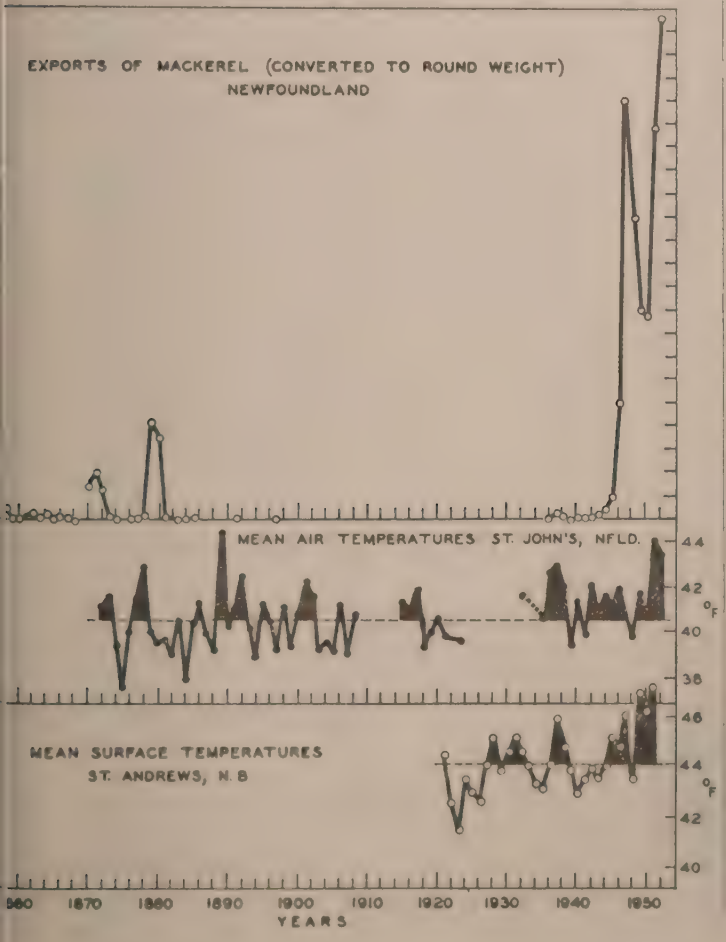
On each figure is shown the mean y air temperatures at St. John's for the ava years between 1872 and 1952 and the yearly surface sea temperatures at St. An N. B. from 1921 to 1951. Extending th each temperature graph is an average line senting the average yearly temperature f whole period at St. John's and at St. Andre most of the years for which temperatur available. It will be noted that although air temperatures from year to year vary a nu of degrees there is a gradually increasing tem ture curve since the 1870's and 1880's wit past twenty years almost all above the av mean temperature for the whole period.

is obvious also that there is a fairly good
n between high and low air temperatures
John's and corresponding periods of high
w temperatures of the sea water at St.
rs. The average line at St. Andrews was
ted from the recent presumably warmer
1921-47 whereas the average airtemper-
at St. John's was derived by including
rlier colder period as well. Thus the
drews average is possibly a half degree
rade or a degree Fahrenheit higher than
uld be to compare with the St. John's
. There is probably a difference of not
nore than 1½ degrees Centigrade between
an sea temperature at St. Andrews and the
ir temperature at St. John's. It is cer-
at because of the location of St. John's
its air temperatures will be strongly affected by the surface temperatures of the nearby Atlantic.

CHANGES IN ABUNDANCE OF MARINE ANIMALS IN SUBAREAS 3 AND 2.

In Subarea 3 there have been only two brief periods of research activity from the Newfoundland Fisheries Research Station, 1931 to 1935, and from 1946 to the present time. The long-term records of marine animal abundance, therefore, are those of marine animals taken commercially and from newspaper records of unusual species. In the following account all the old newspapers have not been thoroughly searched but the fisheries catch and export records have been investigated.

FIGURE 1



Mackerel.

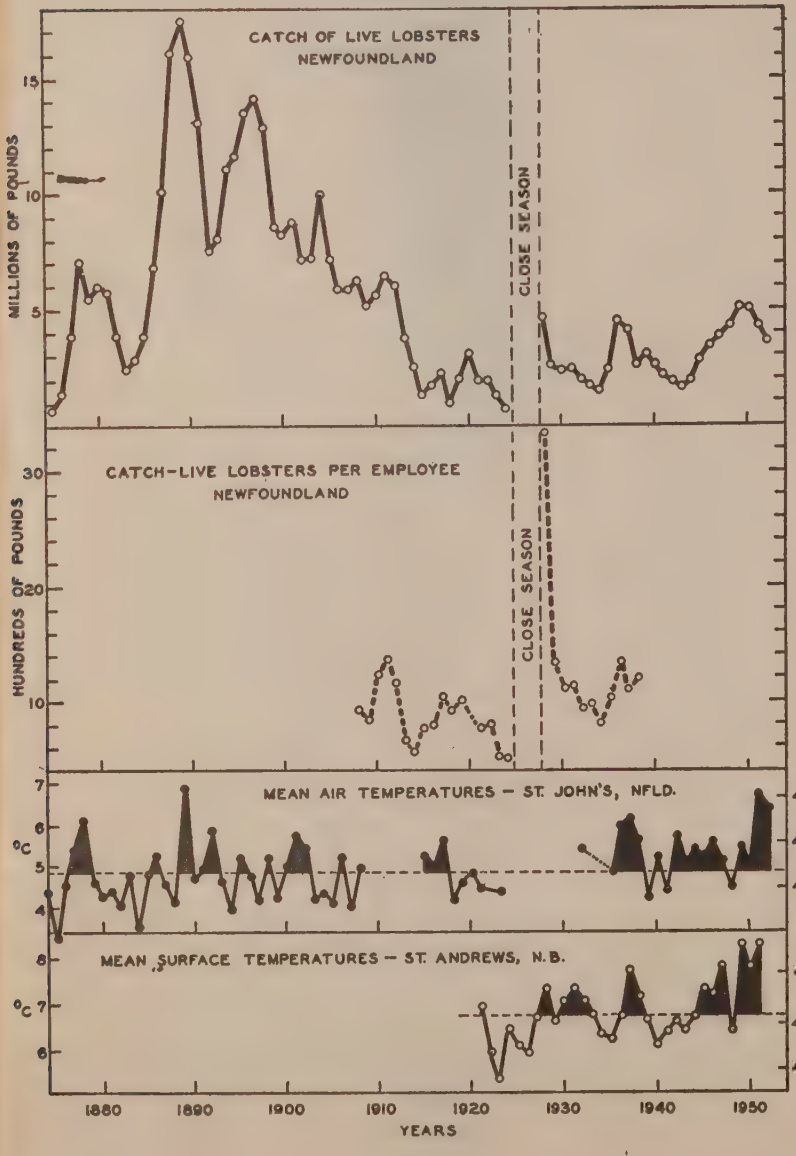
While they were doubtless present on the west coast of Newfoundland, mackerel were apparently absent or extremely scarce from the east coast of the island for many years prior to their recent appearance in numbers. In the senior author's early years at Bonavista in the middle of the east coast, although numerous cod traps were used with mesh small enough to catch mackerel, he can remember seeing only one mackerel.

A statement by Mr. L. G. Hodder from Ireland's Eye in Trinity Bay, one of the present large centers of the fishery, runs as follows— "Mackerel were almost unknown in Trinity Bay prior to the mid 1940's but since then have made their appearance in considerable quantities and a significant mackerel fishery has developed especially during the months of September and October each year."

The export figures for mackerel shown in Figure 1 indicate very small quantities, less than two hundred thousand pounds per year for the earliest figures available, 1856 to 1868; about three to four hundred thousand, 1870-72; and seven to eight hundred thousand pounds in 1879-80. Less than five thousand pounds were exported in each of the years 1883, 1884, 1885, 1891 and 1897, and otherwise there were no further exports until 1936. The exports of mackerel did not rise to two hundred thousand pounds again until after which the exports increased rapidly ranged between approximately two to million pounds from 1947 and 1952.

The recent increase in mackerel appe be an increase in population presumably du recent warm period, the east coast being cold periods a too-low-temperature enviro for the success of this species.

FIGURE II



Lobsters.

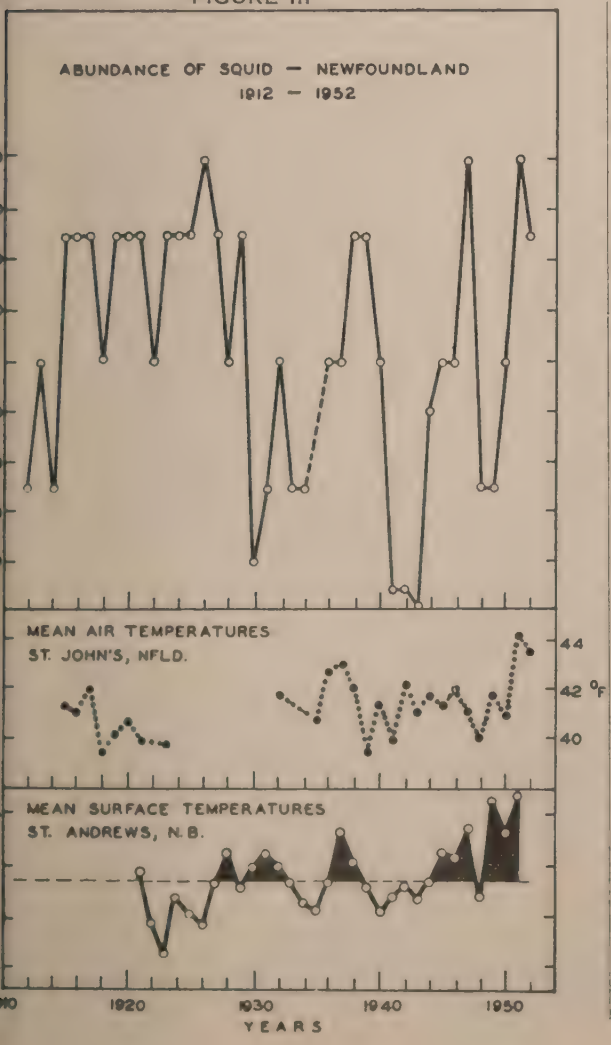
Figure 2 shows the re of the catch of lobsters in foundland to St. John's ai peratures and St. Andrew face sea temperatures. In foundland, lobsters wer caught commercially i 1870's with the highest of sixteen to eighteen m pounds from 1888 to Over six million pounds were caught in almost al between 1886 and 1912 catch was at its lowes between 1915 and 192 the recent twenty years has been a fluctuating b the average progressiv crease in catch (for more plete information on the up to 1939 see Templ 1941). There are only figures available on the n employed in the lobst dustry.

The early large catc resented the fishing-out relatively abundant v stock. Since lobsters in foundland, especially o north-east coast, are a northern limit of their any increase in tempe should be beneficial to th vival of the young and f of trapping the adults.

that the recent improvement in the
s a response to higher temperatures. If
true, it is note-worthy that the
has not been nearly as great as in
Norway and in the north-eastern
in Maine. Summer surface temper-
in Newfoundland lobster producing
ould probably be higher, however, than
northern Maine so that Maine might
nore by increased temperatures.

consider shorter term trends in recent
nce the early nineteen-twenties, it is evi-
a comparison with St. Andrews tempera-
at the three recent prolonged periods of

FIGURE III



below average temperatures correspond fairly well with decreases in the lobster catch. This correlation has already been pointed out by Martin (1953) for the lobster catch in the Maritime Provinces and is apparently due to the fact that temperature controls feeding rate and rate of movement and thus affects the capture of lobsters in baited traps. In the limited information available the catch per employee is similar in trend to the total catch.

Squid

The squid *Illex illecebrosus* is seasonally very common in the Newfoundland inshore area. Squid can usually be caught at a depth of about a hundred fathoms or over on the south-west edge of the Grand Bank in May. They gradually move shoreward across the bank and are numerous in the inshore areas usually in late July or early August, leaving again in November. In some years they may be extremely abundant and in other years scarce or absent. When inshore they are in the warmer and shallower water only several fathoms deep. From its habits one would expect this animal to be associated with rather warm water.

The only long-term information available is qualitative from fisheries reports and other sources indicating abundance. The various degrees of abundance have been given a numerical rating and from this rating the graph below has been drawn (Figure 3). It is seen that contrary to what might be expected there has been no increase in abundance in recent years. There was a period of general abundance with no very bad years between 1915 and 1929, generally lesser abundance from 1930 to 1934, a period of extreme scarcity from 1941 to 1943 and of relative scarcity in 1948 and 1949. There have been more periods of scarcity and greater average scarcity since 1930 than in the fifteen years previous to 1930. We are unable to draw inferences regarding the possible long-term effects of water temperatures.

If short-term local abundance of squid is considered, using St. Andrews temperatures it will be noted that the 1934, 1941 to 1943 and the 1948 lack of abundance occurred during periods of below-average temperatures while the 1930, 1931 and 1949 low abundance occurred with above-average temperatures. The 1922-26 period of considerable abundance occurred during periods of below-average temperatures.

Billfish (*Scomberesox saurus*)

In recent years billfish have often been abundant in Newfoundland waters. Our earliest record is for 1885 when billfish were reported abundant in September in Torbay Harbour. From 1931 to 1934 there are some individual records of billfish by the Fisheries Research Station. In 1936 billfish were plentiful at Bay Bulls and Dildo. The correspondent reported that some had been caught at Bay Bulls thirty years previously. In 1945 the newspaper correspondent from St. Fintan's on the west coast of Newfoundland reports that a school of billfish was encountered. The correspondent says that this fish is a newcomer, he has only heard of them recently. In 1947 in October and November billfish were present in great numbers in Conception Bay. In early October a very large catch was made at Harbour Breton on the south coast while mackerel were being seined. These were the first the correspondent had ever seen. Mr. Colin Storey seined 40 barrels in Trinity Bay in a day during the first week of October. On November 13 and 20, thousands of billfish were driven ashore at Holyrood in a storm. In 1951, billfish were extremely numerous in September and October on the east coast of Newfoundland in Notre Dame, Bonavista, and Trinity Bays. While we cannot be certain of billfish abundance during the years between 1885 and 1931 from absence of records, it seems to be fairly certain judging by the lack of knowledge of billfish among the local population when they became abundant in recent years, that they had not been generally in evidence in numbers for a considerable time previously.

Capelin (*Mallotus villosus*)

The capelin is abundant throughout the Newfoundland area, is near the southern part of its range on the warmer southwest part Newfoundland coast and might thus be ex to show variation in abundance with ch climatic conditions.

In Newfoundland, capelin are used for bait and for fertilizer, consequently cord of former abundance can be found fisheries statistics. Over most of the c rarely fails to appear in numbers. On the part of the south coast and the southern the west coast of Newfoundland, however, time capelin are ready to spawn, inshore te ture conditions in warm periods may often high for the beach spawning which occ all suitable beaches on the colder east coast island.

The latest reports on capelin abundanc Newfoundland area were obtained by a qu naire in 1941 (Templeman, 1948). It w parent that in the period between about 19 1940 or later there was an inshore scar capelin on the warmer parts of the Newfou coast. From the western part of the south with centre at Burgeo, we have the report i from the fisheries inspector that capelin ha plentiful in every year until 1929 and no spawned there since.

From Bay L'Argent and English H West, Fortune Bay, two fisheries ins reported separately in 1941 that this ye the first appearance of the capelin in many The fishery inspector at Port aux Basq ported regarding the area from Cape F Fox Roost in 1941 that there had not be capelin in the area for ten to fifteen years.

Cod

Figures for cod exports and export of dried salt cod are available since 1807 purposes of the graph shown below (Fig the exports in recent years of fillets hav converted to dried salted cod. Unfortu there is no record of the number of fis engaged except for a brief recent period.

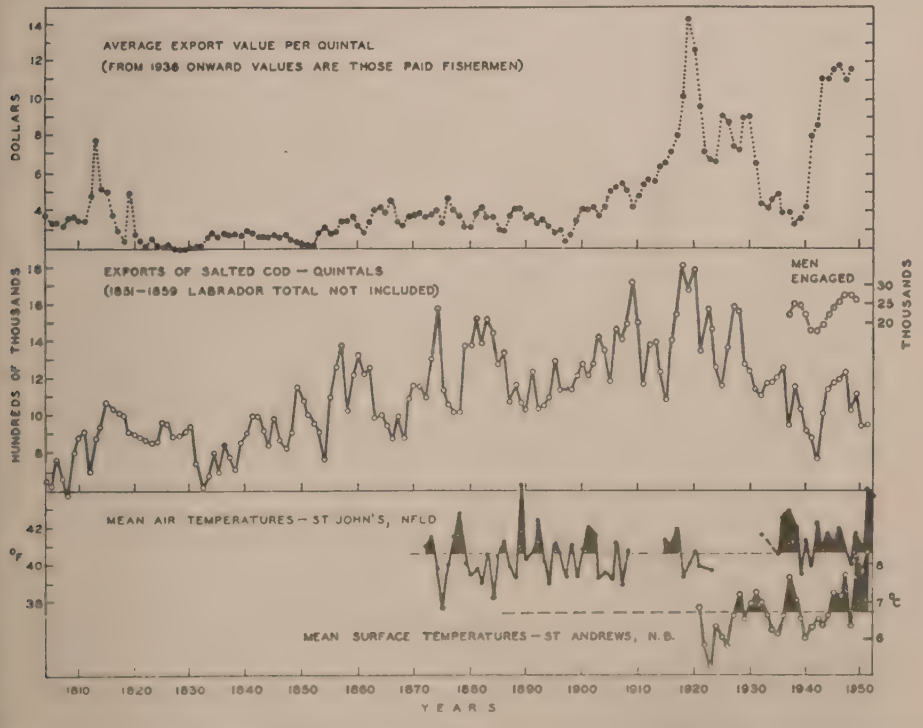
During the period under review, t catch largely inshore in Newfoundland and dor gradually increased to an average of one million eight hundred thousand q

salted cod from 1918-1920 and has since declined to about a million quintals.

e of the increases in catch seem to coin- or follow price increases. In the early he fishery the highest price was reached uring the Napoleonic wars. The general es of the period were soon followed by an in catch with a peak catch in 1815. prices during and immediately after the rld War with a peak price in 1918 also nded with the peak catches of the whole The catch continued at a very high il 1920 when prices fell rapidly and this wed by a decrease in production. The prices of the depression period from 1931 corresponded with a severe reduction in h and the increased prices from 1941 lid not immediately result in the produc- large catch since the number of fisher- lined rapidly through overseas service use during the early war years large of fishermen gave up fishing to work nstruction of military bases in Newfound- ollowing the return of the fishermen to hing trade and with prices still high, the catch increased correspondingly. Still more recently the dory-schooner fishery for cod on the Grand Bank and the schooner fishery for cod on the Labrador coast have been largely abandoned for lack of crews. Many of the fishermen, particularly the younger ones, have again left the fishery to engage in construction and other work. Since these two fisheries have a much greater production per man than the Newfoundland inshore fishery and since there is a reduction in the numbers of inshore fishermen also, there has been an inevitable reduction in total catch. The trawlers which are taking the place of the dory-schooners do not usually fish for cod.

Both the increase in catch from 1870 to 1920 and the decline in the cod catch since 1920 have apparently been in a period of increasing temperatures with the temperatures since 1930 being considerably higher. However, so many other factors are responsible for fluctations in the catch of cod throughout the years that it is very doubtful whether lack of abundance or availability of cod has had anything to do with the overall decline in catch.

FIGURE IV


AVERAGE EXPORT VALUE PER QUINTAL
(FROM 1936 ONWARD VALUES ARE THOSE PAID FISHERMEN)
DOLLARS
EXPORTS OF SALTED COD — QUINTALS
(1831–1859 LABRADOR TOTAL NOT INCLUDED)
HUNDREDS OF THOUSANDS
MEN ENGAGED
THOUSANDS
MEAN AIR TEMPERATURES — ST JOHN'S, NFLD
°F
MEAN SURFACE TEMPERATURES — ST ANDREWS, N.B.
°C
1810 1820 1830 1840 1850 1860 1870 1880 1890 1900 1910 1920 1930 1940 1950
YEARS

References

BJERKAN, PAUL. 1919. Results of the hydrographical observations made by Dr. Johan Hjort in the Canadian Artic waters during the year 1915. Canada, Dept. of Naval Serv., Can. Fish. Exped., (1914-15), 349-403, 2 Pl.

DUNBAR, M. J. 1951. Eastern Atlantic waters. Bull. Fish. Res. Bd. Can., No. 88, 1-131.

HACHEY, H. B. and H. J. McLELLAN. 1948. Trends and cycles in surface temperatures of the Canadian Atlantic. Jour. Fish. Res. Bd. Can., 7 (6), 355-362.

MARTIN, W. R. 1953. Long-term prediction based on climate changes. Paper presented to Comm. Biol. Invest., Ann. Meet. Fish. Res. Bd. Can. (Unpub. MS.).

SMITH, E. H., F. M. SOULE and O. MOSBY. 1937. The Marion and General Greene Expeditions to Davis Strait and Labrador Sea, 1928-1931-1933-1934-1935. Sci. results pt. 2, Physical Oceanography. U. S. Treas. Dept. U.S.C.G. Bull. No. 19, 1-259.

TEMPLEMAN, WILFRED. 1941. The Newfoundland lobster fishery; an account of statistics, methods and important laws. Nfld. Govt. Dept. Nat. Res. Research Bull. 11, 1-42.

TEMPLEMAN, WILFRED. 1948. The life history of the caplin (Mallotus villosus O. F. Müller) in Newfoundland waters. Bull. Nfld. Govt. Lab. No. 17, 1-151.

NTERNATIONAL COMMISSION

FOR THE

NORTHWEST ATLANTIC FISHERIES

REPRINT FROM

ANNUAL PROCEEDINGS

VOL. 3

for the year

1952-53

PART 3

Summary of Canadian Groundfish Research in the Convention Area During 1952

BY WILFRED TEMPLEMAN

Issued from the Headquarters of the Commission
Halifax, N.S., Canada
1953

PART 3

ary of Canadian Groundfish Research in the Convention Area During 1952

SUBAREA 2. By W. TEMPLEMAN

late September, 1952, the "Investigator ried out, as in September, 1951, explora- n Hamilton Inlet Bank, Labrador. A No. was used and many good catches of cod btained, the highest catches being at the 5,000, 6,000, 9,000 and 20,000 pounds per dragging. These good catches were at itre and southern tip of the bank in 89 s and at —0.93°C. and on the central bulge of the bank where the largest catch tained in 132 to 134 fathoms and at a ature of 1.23°C. At latitude 54°21′N. ngitude 54°35′W. in 100 fathoms and C., American plaice were obtained at the 10,000 pounds per hour's dragging and in ne catch cod were taken at the rate of ounds per hour's dragging.

e plaice on this bank were considerably than on the eastern edge of the Grand ut could be readily utilized commercially ostly between 32 and 50 cm. (12½-20 in.) th with modal sizes at about 38 cm. and average sizes of about 40 cm. (16 in). l were of moderate size, almost all being n 40 and 70 cm. (16 and 27½ in). Appro- y one-third to one-quarter were between 2½ pounds and two-thirds to three-quar- re above 2½ pounds.

hydrographic section across the Labra- rent immediately south of Hamilton Inlet as taken between July 26 and August 3.

SUBAREA 3. By W. TEMPLEMAN

ddock.—Location of haddock catches tches of haddock per unit effort by St. trawlers were investigated. Haddock s at St. John's and trawler and "Investi- " catches were sampled for size and scale and otolith collections. Surveys of haddock populations by otter-trawl with shrimp netting in the cod-end were carried out by the "Investigator II". Measurements were made at sea of haddock caught by commercial trawlers and on shore of haddock sizes landed from the same trips so as to obtain the sizes and numbers discarded. Age readings from scales and otoliths were carried out. Vertebral studies and observations of sex and stage of maturity of haddock were continued. Some work was done on factors for converting gutted to round weight.

Cod—Sampling of cod was continued throughout the area with otolith collections and reading for age and growth, measurements of large numbers of fish, vertebral counts, studies of stomach contents, studies of *Porrocaecum* and *Lernaeocera* parasites, and observations on stage of maturity. A large amount of exploration using four 55-foot long-lining boats resulted in the discovery of new fishing grounds several hundred miles in extent and of largely unused populations of large cod in deep water off the north-east coast of Newfoundland. Large cod were numerous in deep water near and below the border of the below-zero centigrade intermediate cold layer. Studies on age and growth of cod showed great differences in growth in the Newfoundland area. The cod of the Labrador coast at 59 cm. length were 13 years of age compared with an age of 6 years at this size on the southern part of the Grand Bank, while the Newfoundland east coast cod were intermediate. No cod tagging has been done since 1950 when 4,715 cod were tagged at St. John's and Fogo. Of these, 3.6% of the Fogo tags and 3.2% of the St. John's tags were returned in 1952. Of the tagged cod recaptured in 1952, 67 of the Fogo recaptures were from inshore Newfoundland areas and 3 from the northern half of the Grand Bank, while of the

St. John's 1952 recaptures 75 were recaptured in inshore Newfoundland areas, one in southern Labrador and 12 from the northern half of the Grand Bank. Information was obtained on conversion factors from gutted to round weight. Studies were made of yield and vitamin A values of oil from cod livers.

Redfish—Explorations of redfish populations by the "Investigator II" were continued with large numbers of measurements and sampling of the populations for vertebral number, age and growth as determined from otoliths, sex and stage of maturity and distribution of the redfish parasite *Sphyrion lumpi*. Investigations on the south-western edge of the Grand Bank in June showed, as in 1952, redfish increasing considerably in size and the percentage of females gradually increasing proceeding deeper from 100 to 200 fathoms. Researches were continued on the yield and vitamin A values of the oil from redfish livers and redfish waste.

American plaice and witch flounder—Large numbers of measurements of these species were made in catches of the "Investigator II" and by commercial trawlers. Samples were taken throughout the year and in many areas for vertebral number, fin ray count, sex and stage of maturity, and otoliths were taken for age determination.

A rough comparison was made between catches of witch flounder in otter-trawling by the "Investigator II" and those by a smaller Danish seiner in the same area. The advantage lay with the seiner.

Hydrography—Hydrographic sections from 47°latitude southward on the Grand Bank and St. Pierre Bank were covered by the "Investigator II" in March and April. In July-August sections were taken across the Labrador current off Bonavista, and all the spring stations from 47° latitude southward were repeated. The general hydrographic picture showed high spring temperatures on the Grand Bank as a hold-over from the high summer temperatures of the previous year. Meanwhile north of the Grand Bank and particularly in Labrador more and colder low temperature water existed and this gradually flowed southward during at least the early summer. Thus the bottom water on the Grand Bank at most stations colder in July-August tha March-April.

SUBAREA 4. By A. W. H. NEEDLER & W. R. MA

Part of the Canadian groundfish rese in Subarea 4 is particularly of national inte development of fishing methods such as D seining; exploration for unexploited in resources such as the flounder, *Pseudopleur tes*; and life history studies of groundfish para such as *Porrocaecum*. The greater part of research program is of international inte identification of stocks; relation of fisher hydrography; and studies of abundance, rec ment, growth and mortalities. Research in latter field during 1952 is summarized below.

Identification of Stocks—A summa the current status of our knowledge of principal groundfish stocks in Subarea 4 been submitted to the Commission for consi tion at the Third Annual Meeting, (Part 4 All four of the important groundfish sp (cod, haddock, redfish and halibut) inclu number of stocks distinct from one another from stocks of adjacent subareas. Migra populations of cod and haddock, living on inshore and offshore fishing grounds, have observed in the eastern part of Subarea 4.

A manuscript describing the results of tagging from 1930 to 1940 has been prepare publication. Some 22,000 cod were tagged about 2,500 of these recaptured. The resu picture of cod populations includes inform on divisions of stocks and their movemen relation to hydrographic conditions, sexual m ity and feeding, all of basic value to a consi tion of conservation requirements.

Four field men carried out regular sam of commercial landings of groundfish from inshore and offshore grounds. The resu observations on growth, year-class strength infection with parasites are contributing precise definitions of the large number of po tions of each of the commercially impo groundfish species in Subarea 4.

drography—The Atlantic Oceanograph- rip carried out regular quarterly cruises in of Fundy, Scotian Shelf and Gulf of St. ce areas. A long-term program of more t observations has been continued at nine points.

ursions of "slope water" during 1952 had und effect on the fishing areas of the Sco- elf. During the past few years surface temperatures have reached the highest values on record and this climatic change l an important effect on certain fisheries. bservations are helping to distinguish s changes which are man-made, and controllable, from those which are nat-

tch Statistics—The statistical data col- or Subarea 4 have improved during 1952 e establishment of a statistical unit of undfish research group at Halifax, N. S. s of offshore landings, area fished and effort (from offshore landing records and s' log books) provide the basis for com- of statistical reports, including those l by the Commission. Statistics of small- ndings are compiled monthly by officers Department of Fisheries and summaries ricts are available in annual published s. Representative districts are sampled groundfish research group for data on s related to fishing effort.

1952, cod landings continued to make up of groundfish landings from Subarea 4. s are again close to those observed in the having declined gradually from the peak 400 million pounds (200 thousand metric 1945. Fishing activity was greatly cur- during war years and the accumulated resulting from this reduced effort and ntinued good recruitment and growth d good fishing; cod abundance as measur- catch-per-effort reached a maximum in d 1945. With increased fishing effort trawlers in post-war years, cod abundance lined and this is particularly apparent cod of 10 pounds and over. In 1952, ndance of large cod was at a low level throughout the year and cod landings were reduced accordingly. Landings of scrod cod (1½ to 2½ lb.) continued to be small and the quantities of small cod discarded at sea were negligible.

Annual haddock landings from Subarea 4 fluctuate appreciably, now averaging about 80 million pounds (40 thousand metric tons). Regular observations at sea on commercial trawlers showed that about half the haddock caught during the months of May to September, 1952, were discarded at sea, being below marketable size.

Halibut landings from Subarea 4 average about four million pounds (two thousand metric tons). Greatly reduced halibut fishing effort during war years resulted in an accumulated stock which was quickly exploited in post-war years. In 1952, landings were still above the long-term average.

Vital Statistics—Commercial groundfish catches were again sampled regularly throughout the area for sizes and ages of fish landed. These data, together with catch and effort statistics, provide information on recruitment, growth and total mortalities. A laboratory technician made about 9,000 age determinations during 1952. A few preliminary observations on the 1952 data may be made.

Cod. Total mortality is highest off western Nova Scotia, relatively low in the Gulf of St. Lawrence and at an intermediate level on eastern and offshore Nova Scotian grounds. The 1939, 1941 and 1943 year-classes have made important contributions to offshore catches during recent years. Mortality rates appear to have increased and relatively strong year-classes now make insignificant contributions to landings of large cod (over 10 pounds or 10 years).

Haddock growth is slower than in Subarea 5 but mortality rates are not appreciably different. Great variation is found in year-class strength, the 1943 year-class being particularly important to the fishery. It is predicted that present recruitment will result in continued good availability of haddock in Subarea 4 during 1953.